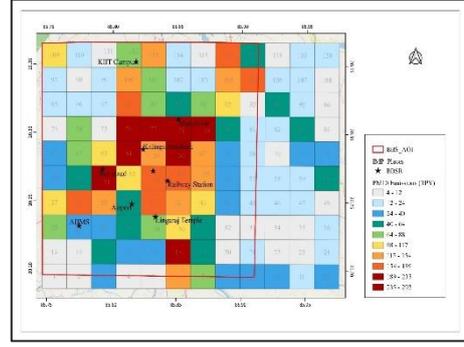
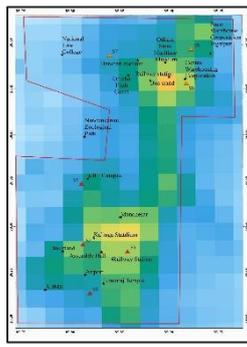
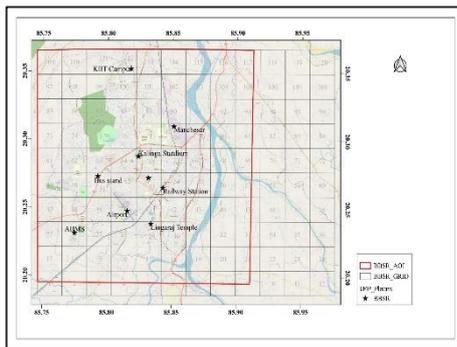
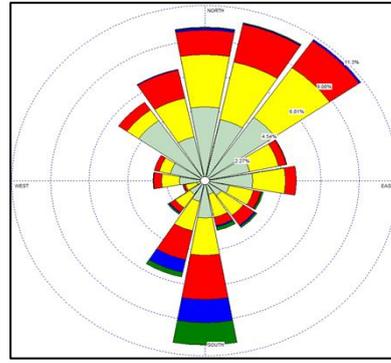
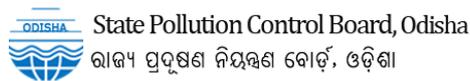


## FINAL REPORT

# Emission Inventory and Source Apportionment Study of Bhubaneswar Region in Odisha



Submitted to



ରାଜ୍ୟ ପ୍ରଦୂଷଣ ନିୟନ୍ତ୍ରଣ ବୋର୍ଡ଼, ଓଡ଼ିଶା

**State Pollution Control Board, Odisha (OSPCB)**

Submitted by



**Environment Research Laboratory  
The Automotive Research Association of India (ARAI), Pune**

**December 2024**

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## **Disclaimer**

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Hersbach, H. et al., (2018) was downloaded from the Copernicus Climate Change Service (2023). The results contain modified Copernicus Climate Change Service information 2020. Neither the European Commission nor ECMWF is responsible for any use that may be made of the Copernicus information or data it contains.

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## Abbreviations

AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model

AQI: Air Quality Index

ARAI: Automotive Research Association of India

BAU: Business-as-usual

BRTS: Bus rapid transit system

BS-X: Bharat Stage (I to VI)

CAAQM: Continuous Ambient Air Quality Monitoring Station

CM: Crustal materials

CO: Carbon Monoxide

CPCB: Central Pollution Control Board

DG: Diesel Generators

EC: Elemental carbon

EF: Emission factors

EV: Electric Vehicle

FCBTK: Fixed chimney bull trench kiln

GCP: Good construction practices

GIS: Geographic Information System

GoI: Government of India

MoEFCC: Ministry of Environment, Forest and Climate Change

OSPCB: State Pollution Control Board, Odisha

MRTS: Mass rapid transit system

MSL: Mean Sea Level

TPY: Tonnes Per Year

VKT: Vehicle Kilometres Travelled

MSW: Municipal Solid Waste

NCAP: National Clean Air Project

NFC: No further control

NGO: Non-Governmental organisation

NMT: Non-motorised transport

NOx: Nitrogen Oxides

NMVOCs: Non-Methane Volatile Organic Compounds

NAAQS: National Ambient Air Quality Standards

OC: Organic carbon

PM: Particulate Matter

PM10: Particulate Matter having aerodynamic diameter less than or equal to 10 microns

PM2.5: Particulate Matter having aerodynamic diameter less than or equal to 2.5 microns

QA: Quality assurance

QC: Quality control

SC-I: Scenario I

SC-II: Scenario II

sL: Silt Loading

SNA: Sulphate, Nitrate and Ammonium

SO2: Sulfur Dioxide

SS: Sea salts

TE: Trace elements

USEPA: United States Environmental Protection Agency

ZIF: Zone of influence

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## **Executive Summary**

Air pollution has become a serious problem recently and it is considered as a major challenge for pollution and health regulatory agencies around the world. The Central Pollution Control Board (CPCB), New Delhi has identified 131 cities in India where the prescribed annual National Ambient Air Quality Standards (NAAQS) are violated. In this regard, Ministry of Environment, Forest and Climate Change (MoEFCC) have launched National Clean Air Program (NCAP) in 2019 which aims to reduce the national level PM<sub>2.5</sub> and PM<sub>10</sub> concentrations.

To address the air pollution issues of the Bhubaneswar region, State Pollution Control Board, Odisha (OSPCB) has entrusted The Automotive Research Association of India (ARAI), Pune to carry out a detailed study on “Emission Inventory and Source Apportionment Study of Bhubaneswar Region in Odisha”. The main aim of this study is to identify and characterize various emission sources in Bhubaneswar region of Odisha and help the regulatory agencies in prioritizing the actions for improving the air quality. The major objectives of the study are:

- To carry out particulate matter (PM<sub>10</sub> & PM<sub>2.5</sub>) source apportionment using receptor modelling approach for Bhubaneswar region.
- To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Bhubaneswar region.

This study has six major components 1. air quality sampling and chemical analysis, 2. receptor modelling, 3. emission inventory, 4. dispersion modelling, 5. evaluation of control scenarios and air quality benefits and 6. Air quality action plan. The highlights of these components are presented in subsequent sections.

## **Study Area**

Bhubaneswar region, located at approximately 20.8833° N latitude and 86.0833° E longitude in the Khordha district and it is the capital city of Odisha in eastern India, is renowned for its rich historical heritage and vibrant culture. The city, often referred to as the "Temple City of India," boasts ancient temples like the 11<sup>th</sup> century Lingaraj Temple dedicated to Lord Shiva, attracting pilgrims and tourists alike with its architectural splendour and spiritual significance. In recent years, Bhubaneswar has undergone rapid urban development, emerging as a pivotal economic and educational hub in the region. As one of India's planned cities, it

serves as a major administrative and commercial centre, fostering growth in sectors ranging from information technology to education.

### **Air quality sampling and chemical analysis**

Based on the reconnaissance surveys and inputs from OSPCB four sampling locations were identified for this study which represent various land-use patterns, and include 1 background site, 2 residential sites, and 1 industrial site. These sites are located in different parts of Bhubaneswar region and can provide an integrated insight into the characteristics of PM<sub>2.5</sub> and PM<sub>10</sub> over Bhubaneswar region. Table ES-1 and Fig. ES-1 provides details of the monitoring locations. The ambient PM<sub>2.5</sub> and PM<sub>10</sub> samples were collected in the study area, during two critical seasons i.e. winter (December 12 to 27, 2022) and summer (April 11 to 29, 2023).

TABLE ES-1 GEOGRAPHIC INFORMATION OF THE SELECTED SAMPLING SITES IN BHUBANESWAR REGION

Code	Location	Latitude	Longitude	Category
S1	Gokhibaba Ashram, Sudarpada	20° 13' 38.94" N	85° 49' 11.72" E	Background
S2	OSPCB Head Office, Nayapalli	20° 16' 48.01" N	85° 48' 46.47" E	Mixed
S3	Office of Chief Instructress Home Economic Training Centre, Jharpada	20° 16' 20.62" N	85° 51' 29.19" E	Residential
S4	RO Office SPCB, Patia	20° 20' 45.81" N	85° 48' 42.12" E	Industrial

The ambient PM<sub>2.5</sub> and PM<sub>10</sub> samples were collected using multi-channel speciation samplers for 24 hours at a flow rate of 16.7 LPM. Teflon filters were used for measurement of gravimetric mass, elemental concentrations, and water-soluble ions while the quartz-fiber filters were analysed for carbonaceous materials. The Teflon filters were subjected to analysis of elements using Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRF) method while the water-soluble inorganic ionic components were determined using ion chromatography method. Similarly, the quartz filter samples were used for the analysis of organic carbon (OC) and elemental carbon (EC) using a Thermal/Optical Carbon Analyzer (DRI Model 2001A; Desert Research Institute, USA) following IMPROVE\_A protocol (Chow et al. 2007). After the carbon fraction analysis, remaining part of the quartz filter papers were subjected to molecular markers (alkanes, hopanes, amides, levoglucosan and stigmaterol) analysis using Gas chromatography – mass spectrometry (GC-MS) method.

In addition to particulate matter, the present study also analysed the levels of gaseous pollutants such as SO<sub>2</sub> and NO<sub>2</sub> and Volatile Organic Compounds (VOCs) such as Benzene, Toluene, Ethyl Benzene and Xylene, during winter season.

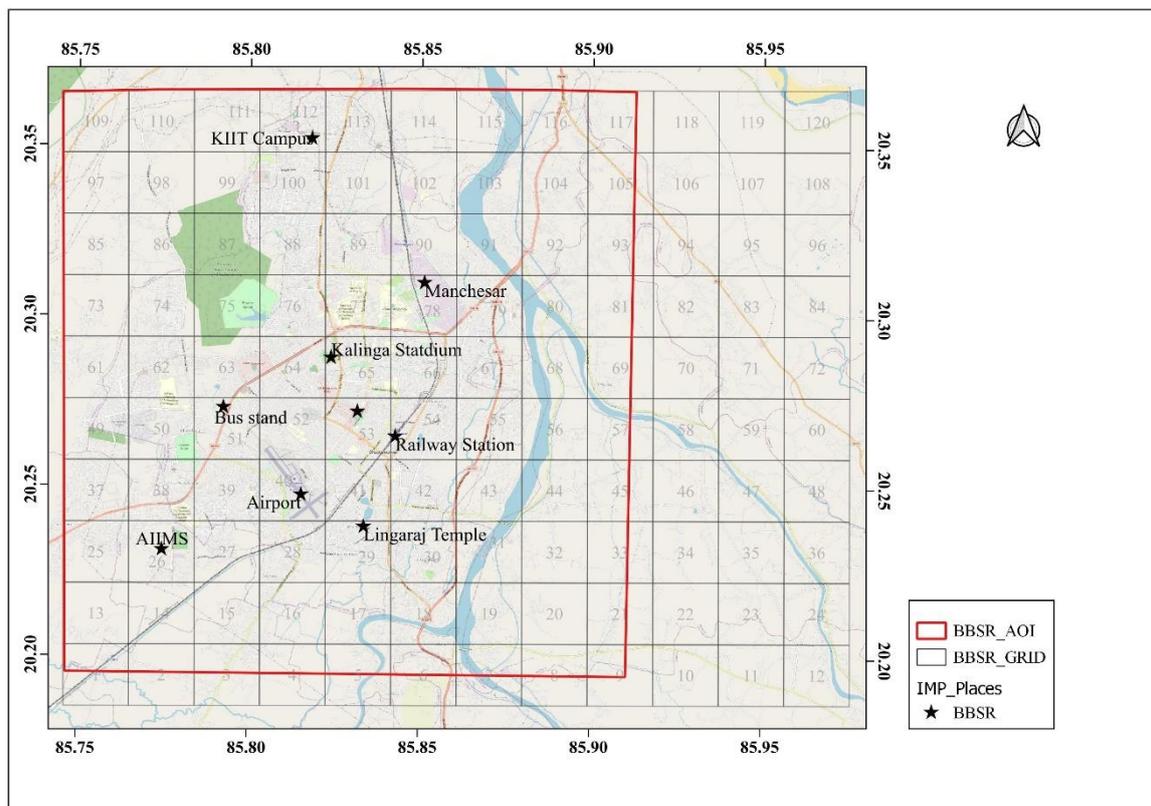


FIGURE ES-1 BHUBANESWAR REGION MAP SHOWING DIFFERENT LAND-USE CLASSES. THE VIOLET COLOURED PINS SHOW THE LOCATION OF FOUR SAMPLING SITES SELECTED FOR SOURCE APPORTIONMENT STUDY

The winter-season mean PM<sub>2.5</sub> and PM<sub>10</sub> mass concentrations over all sites were 81.9 and 183.1 µg/m<sup>3</sup>, respectively. The highest seasonal mean PM<sub>2.5</sub> concentrations were observed at S2 i.e. OSPCB Head Office (86.6 µg/m<sup>3</sup>) while the lowest were recorded at S3, i.e. Office of Chief Instructress Home Economic Training Centre (77.7 µg/m<sup>3</sup>). Similarly, the highest seasonal mean PM<sub>10</sub> concentrations were observed at S2 i.e. OSPCB Head Office (198.0 µg/m<sup>3</sup>) while the lowest were recorded at S1 i.e. Gokhibaba Ashram (175.9 µg/m<sup>3</sup>). The mean value of PM<sub>2.5</sub> to PM<sub>10</sub> ratios during the study period over all sites was found to be 0.45, varying from 0.31 to 0.63, which in turn indicates a mix of dusty and combustion sources.

The summer-season mean PM<sub>2.5</sub> and PM<sub>10</sub> mass concentrations over all sites were 43.3 and 93.8 µg/m<sup>3</sup>, respectively. The highest seasonal mean PM<sub>2.5</sub> concentration was observed at S2 i.e. OSPCB Head Office (48.5 µg/m<sup>3</sup>) while the lowest was recorded at S1 i.e. Gokhibaba

Ashram ( $37.3 \mu\text{g}/\text{m}^3$ ). Similarly, the highest seasonal mean  $\text{PM}_{10}$  concentration was observed at S3 i.e. Office of Chief Instructress Home Economic Training Centre ( $117.5 \mu\text{g}/\text{m}^3$ ) while the lowest was recorded at S1 i.e. Gokhibaba Ashram ( $78.4 \mu\text{g}/\text{m}^3$ ). The mean value of  $\text{PM}_{2.5}$  to  $\text{PM}_{10}$  ratios during the summer season over all sites was found to be 0.49, varying from 0.22 to 0.84, which in turn indicates dominance of dusty sources.

Based on the chemical speciation analysis, the PM chemical components were grouped into six categories i.e. organic matter (OM), elemental carbon (EC), sulphate, nitrate and ammonium ions (together referred to as SNA), chloride ions, crustal materials (CM) and other trace elements (TE). The reconstructed PM mass is then calculated and compared with observed gravimetric mass. The reconstructed mass was significantly related to gravimetric mass in both winter and summer seasons. The squared correlation coefficient,  $R^2$  is found to be 0.80 (winter) and 0.89 (summer) for  $\text{PM}_{2.5}$  whereas it is found to be 0.90 (winter) and 0.98 (summer) for  $\text{PM}_{10}$ , respectively. During the winter season, the fractions of major chemical compositions followed the order of  $\text{OM} > \text{SNA} > \text{EC} > \text{CM} > \text{TE} > \text{SS}$  in both  $\text{PM}_{2.5}$  whereas this order changed to  $\text{OM} > \text{SNA} > \text{CM} > \text{EC} > \text{TE} > \text{SS}$  in  $\text{PM}_{10}$ . Similarly, during the summer season, the fractions of major chemical compositions followed the order of  $\text{OM} > \text{SNA} > \text{EC} > \text{CM} > \text{TE} > \text{SS}$  in  $\text{PM}_{2.5}$  whereas this order changed to  $\text{OM} > \text{SNA} > \text{CM} > \text{EC} > \text{TE} > \text{SS}$  in  $\text{PM}_{10}$ . Additionally, chemical ratios such as  $\text{OC}/\text{EC}$ ,  $\text{Cl}^-/\text{Na}^+$ ,  $\text{K}^+/\text{OC}$ ,  $\text{K}^+/\text{EC}$ ,  $\text{NO}_3^-/\text{SO}_4^{2-}$  and degree of neutralization (DON) were also used as indicators to qualitatively assess the contributions from air polluting sources.

As discussed earlier, the gaseous pollutants i.e.  $\text{SO}_2$  and  $\text{NO}_2$  and VOCs (i.e. Benzene, Toluene, Ethyl Benzene and Xylene) were also monitored at four sampling locations in Bhubaneswar region, during the winter season sampling period i.e. December 12-27, 2022. The winter season  $\text{SO}_2$  concentrations were less than  $5 \mu\text{g}/\text{m}^3$  at all sites and hence are reported as Below Detection Limit (BDL). The winter season mean concentrations of  $\text{NO}_2$  are observed to be  $22.4 \mu\text{g}/\text{m}^3$  at Gokhibaba Ashram, Sundarpada (S1),  $37.4 \mu\text{g}/\text{m}^3$  at OSPCB Head Office, Nayapalli (S2),  $18.9 \mu\text{g}/\text{m}^3$  at CIHETC, Jharpada (S3) and  $29.9 \mu\text{g}/\text{m}^3$  at RO Office, SPCB, Patia (S4). In case of VOCs, the winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites ranged from  $15.3$  to  $41.4 \text{ ng}/\text{m}^3$ ,  $69.7$  to  $263.4 \text{ ng}/\text{m}^3$ ,  $115.4$  to  $2602.0 \text{ ng}/\text{m}^3$  and  $242.2$  to  $2695.1 \text{ ng}/\text{m}^3$ , respectively.

## **Receptor modelling**

The data generated from chemical analysis of ambient PM samples along with source profiles is then used for receptor modelling assessment. In the present study, the US EPA-Chemical Mass Balance Model (CMB V8.2; Coulter 2004) is used to apportion the sources of PM<sub>2.5</sub> and PM<sub>10</sub> particles in Bhubaneswar region. The CMB model uses ambient pollutant concentrations, their chemical composition, and the chemical composition of sources i.e. source profiles, to estimate the relative contribution of each source to ambient concentrations at a given location.

Source contributions to fine and coarse particulate matter i.e. PM<sub>2.5</sub> and PM<sub>10</sub> were calculated with the CMB model for the individual daily samples for four sampling sites in Bhubaneswar region. Five pollution sources were apportioned using the mean concentration data including i) transport (TRAN), ii) road and construction dust (DUST), iii) biomass and solid waste combustion (BCOM), iv) industry and thermal powerplants and fugitive dust (INDU) and v) secondary aerosols (SECY). The residual/un-apportioned mass is considered to be originating from the unidentified sources (UNID). The results from individual sites are averaged to calculate the regional mean source contributions and are explained below.

Overall, the winter-time PM<sub>2.5</sub> mass at Bhubaneswar (Fig. 51) are found to be dominated by solid waste and biomass combustion sector with highest contribution of 37.6%. The other sources of PM<sub>2.5</sub> at Bhubaneswar are identified as transport (30.7%), secondary aerosols (12.3%), dust (10.5%), and industry (1.1%). Similarly, the winter-time PM<sub>10</sub> mass at Bhubaneswar is found to be dominated by solid waste and biomass combustion (29.1%), followed by dust (23.2%), secondary aerosols (17.7%), transport (18.6%), and industry (1.1%). Additionally, about 7.8% and 10.3% mass of PM<sub>2.5</sub> and PM<sub>10</sub> remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

The summer-time PM<sub>2.5</sub> mass at Bhubaneswar (Fig. 52) is found to be dominated by transport with highest contribution of 33.1%. The other summer-time sources of PM<sub>2.5</sub> at Bhubaneswar region are identified as solid waste and biomass combustion (27.4%), secondary aerosols (17.4%), dust (16.0%) and industry (0.9%). Similarly, the summer-time PM<sub>10</sub> mass at Bhubaneswar is also found to be dominated by dust (28.9%), followed by secondary aerosols (22.4%), transport (19.2%), solid waste and biomass combustion (19.0%), and industry (0.7%). Additionally, about 6.8% and 10.5% mass of PM<sub>2.5</sub> and PM<sub>10</sub> remained un-apportioned during

the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

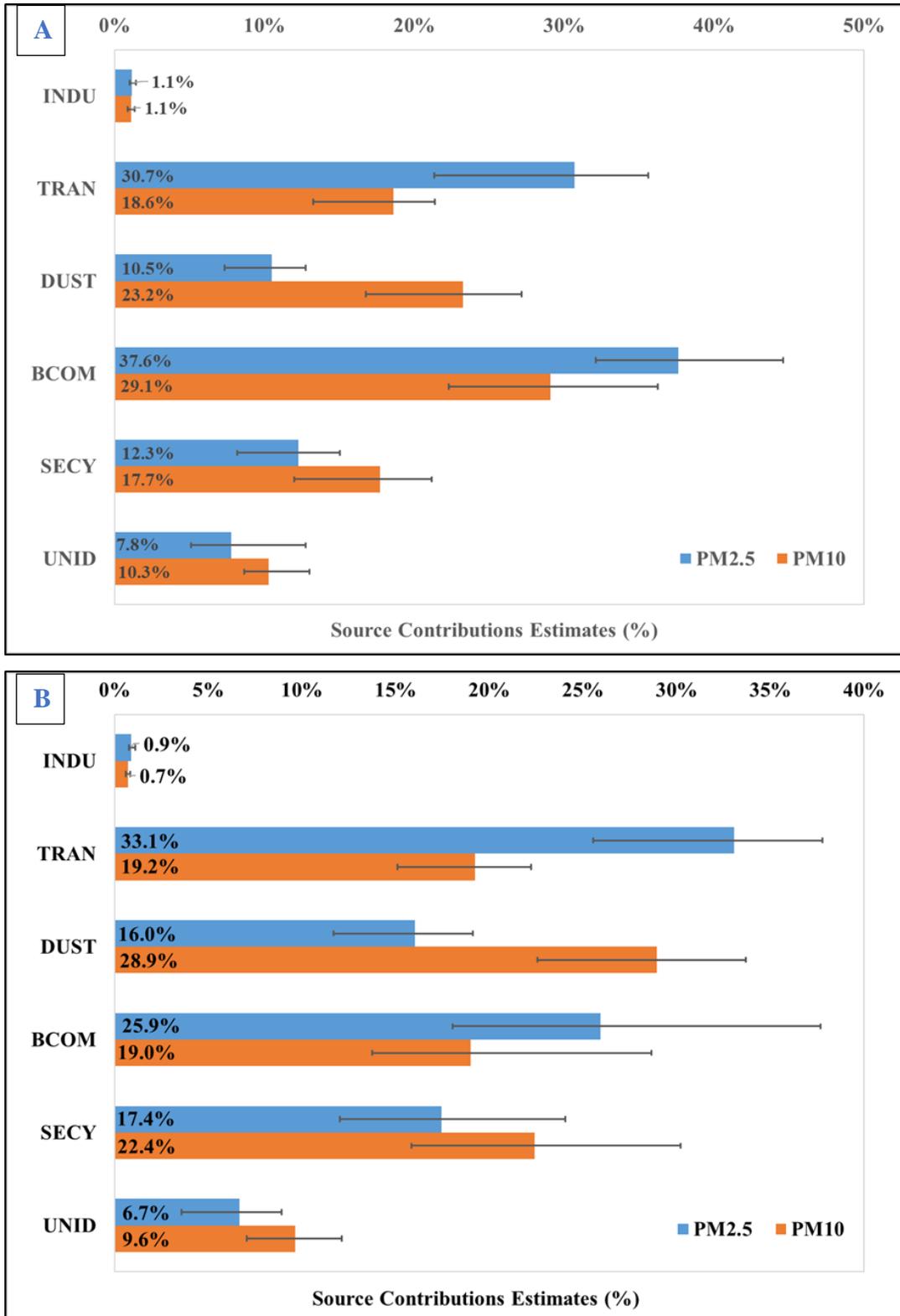


FIGURE ES-2 CITY-LEVEL SOURCE CONTRIBUTION ESTIMATES (SCE) FOR BHUBANESWAR REGION USING CMB RECEPTOR MODEL DURING WINTER (A) AND SUMMER (B) SEASONS

## **Emission Inventory**

The development of emission inventory for Bhubaneswar region involved quantification of emission loads originating from sectors including: Transport, Re-suspended road dust, Open Waste Burning, Residential, Industries, Diesel generators, Hotels, Restaurants and Bakeries, Crematoria, Brick kilns, Construction, Windblown riverbed erosion dust, and Aviation activities. The air pollutants considered in this study includes: particulate matter having aerodynamic diameter less than or equal to 10 microns (PM<sub>10</sub>), particulate matter having aerodynamic diameter less than or equal to 2.5 microns (PM<sub>2.5</sub>), sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). The spatial resolution of emission inventory is: 2 x 2 km<sup>2</sup> over the study area while the temporal resolution is monthly.

The emission inventory development started with data collection activity. Two types of data collection approaches are used in this study i.e. primary and secondary data collection. The first approach i.e. primary data collection involves field surveys at identified locations for residential, commercial, and industrial fuel consumption, parking lot surveys to understand details of vehicle fleet, classified vehicle surveys to understand traffic count for various vehicle types. The second approach i.e. secondary data collection involves extracting relevant data from published reports, research papers, and government department website. The emission inventory development followed a bottom-up approach for estimation of emissions using activity rates for each sector and the measured emission factors (EFs) in India wherever possible. The bottom-up approach uses source-specific and category-specific data at the most refined spatial level to estimate emissions. The emissions estimated for individual sources are summed up to obtain a regional emissions inventory.

The overall baseline emission inventory (Year 2022) for the Bhubaneswar region is presented in Table ES-2, while the pollutant wise contribution is shown in Fig. ES-3. The spatial distribution of the pollutants over Bhubaneswar region is provided in Fig. ES-4, ES-5 and ES-6. The total PM<sub>10</sub> emission load in the Bhubaneswar region is estimated to be 7,711 tonnes per year. The top four contributors to PM<sub>10</sub> emissions are resuspended road dust (39.2%), followed by transport (20.4%), open waste burning (11.5%), and hotel, restaurants and bakeries (9.6%). Similarly, PM<sub>2.5</sub> emission load in the Bhubaneswar region is estimated to be 4,356 tonnes per year. The top four contributors to PM<sub>2.5</sub> emissions are transport (32.5%), open waste burning (18.9%), resuspended road dust (16.8%), and hotel, restaurants and

bakeries (11.3%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

TABLE ES-2 EMISSION INVENTORY (TONNES PER YEAR) FOR BHUBANESWAR REGION IN YEAR 2022

Sector	PM10	PM2.5	SO <sub>2</sub>	NO <sub>x</sub>	CO	NM VOC
Transport (TRAN)	1575 ± 425	1417 ± 383	24 ± 4	13029 ± 6931	38788 ± 20639	25401 ± 13414
Road dust re-suspension (RDST)	3021 ± 753	731 ± 182	NA	NA	NA	NA
Residential (RESI)	767 ± 397	488 ± 252	429 ± 70	298 ± 154	6946 ± 3602	2271 ± 0
Waste burning (WAST)	886 ± 493	823 ± 458	56 ± 31	127 ± 70	4242 ± 2360	918 ± 1222
Hotels, Restaurants, Bakeries and Open eateries (HRBE)	741 ± 401	492 ± 266	369 ± 85	164 ± 88	3062 ± 1660	430 ± 2296
Construction (CONS)	297 ± 64	74 ± 16	NA	NA	NA	NA
Diesel Generators (DSGN)	347 ± 179	299 ± 154	215 ± 52	3257 ± 1690	703 ± 364	4265 ± 219
Wind-blown Riverbed Erosion dust (WBDT)	12 ± 3	3 ± 0	NA	NA	NA	NA
Industries (INDU)	11 ± 2	7 ± 1	1 ± 0	2 ± 0	174 ± 35	1 ± 0
Brick Kilns (BRIC)	14.7 ± 8	3 ± 1	10 ± 5	0 ± 0	49 ± 28	2 ± 1
Crematoria (CREM)	39 ± 19	19 ± 9	0.8 ± 0	5 ± 2	196 ± 100	109 ± 1
Aviation (ACFT)	0.003 ± 0	0.003 ± 0	0.021 ± 0	0.259 ± 0	0.537 ± 0	0.277 ± 55
<b>Total</b>	<b>7711 ± 2751</b>	<b>4356 ± 1728</b>	<b>1104 ± 250</b>	<b>16882 ± 8938</b>	<b>54162 ± 28792</b>	<b>33397 ± 17256</b>

NA: indicates the emissions quantification is not applicable for a particular sector. The value after ± indicates uncertainty in emission estimates (tonnes).

The gaseous pollutants, included in the study were SO<sub>2</sub>, NO<sub>x</sub>, CO and NMVOC. The SO<sub>2</sub>, NO<sub>x</sub>, CO and NMVOC emission loads for year 2022 in the study domain are estimated to be 1104, 16882, 54162 and 33397 tonnes per year, respectively.

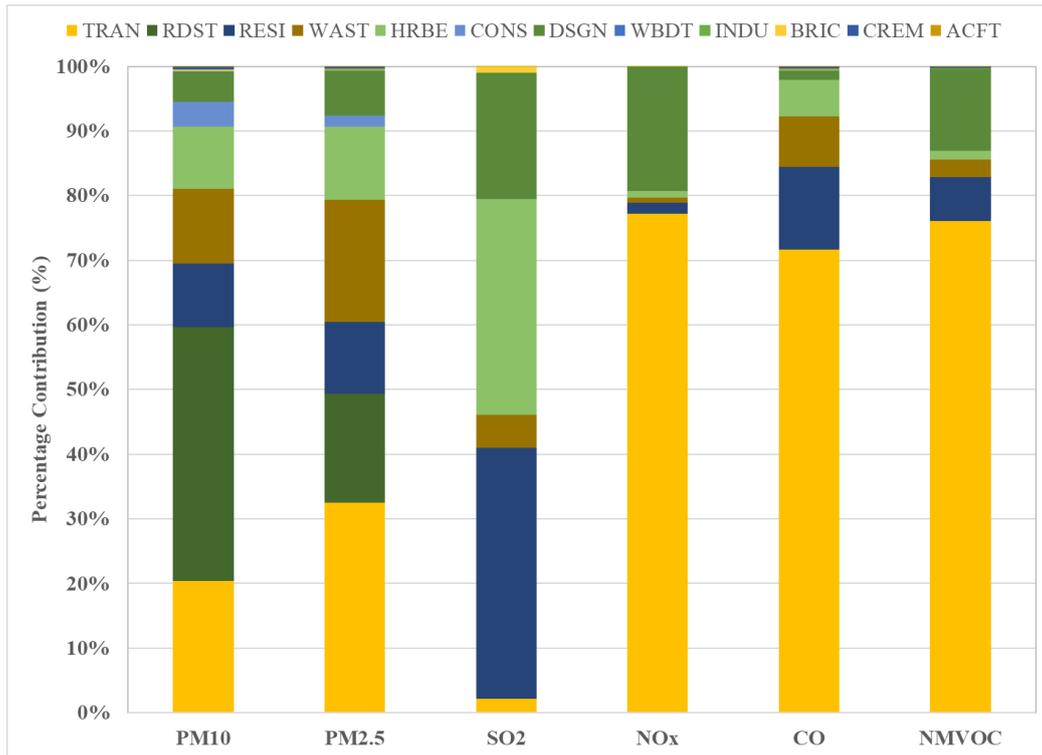


FIGURE ES-3 SECTOR-WISE CONTRIBUTION TO AIR POLLUTANT EMISSIONS OF A) PM<sub>10</sub>, B) PM<sub>2.5</sub>, C) SO<sub>2</sub>, D) NO<sub>x</sub>, E) CO AND F) NMVOC IN BHUBANESWAR REGION IN 2022

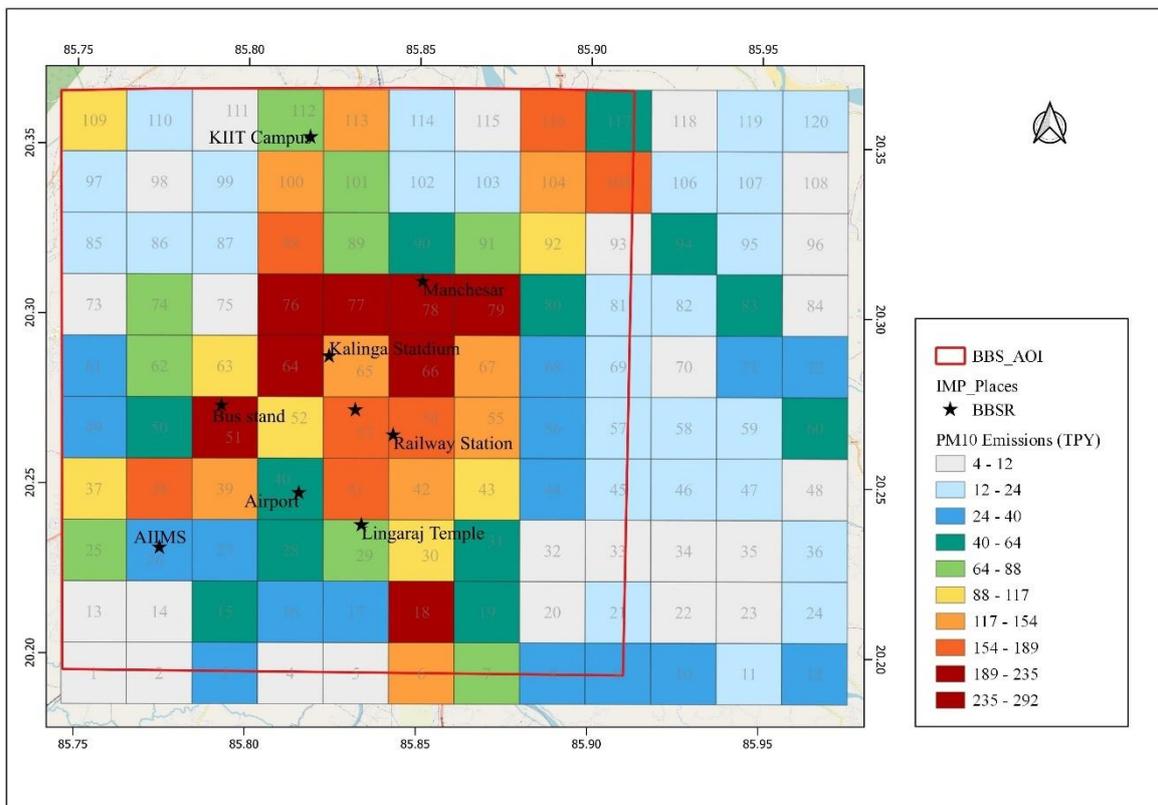


FIGURE ES-4 SPATIAL DISTRIBUTION OF AIR POLLUTANT EMISSIONS OF A) PM<sub>10</sub>, (TONNES PER YEAR) IN BHUBANESWAR REGION IN 2022.

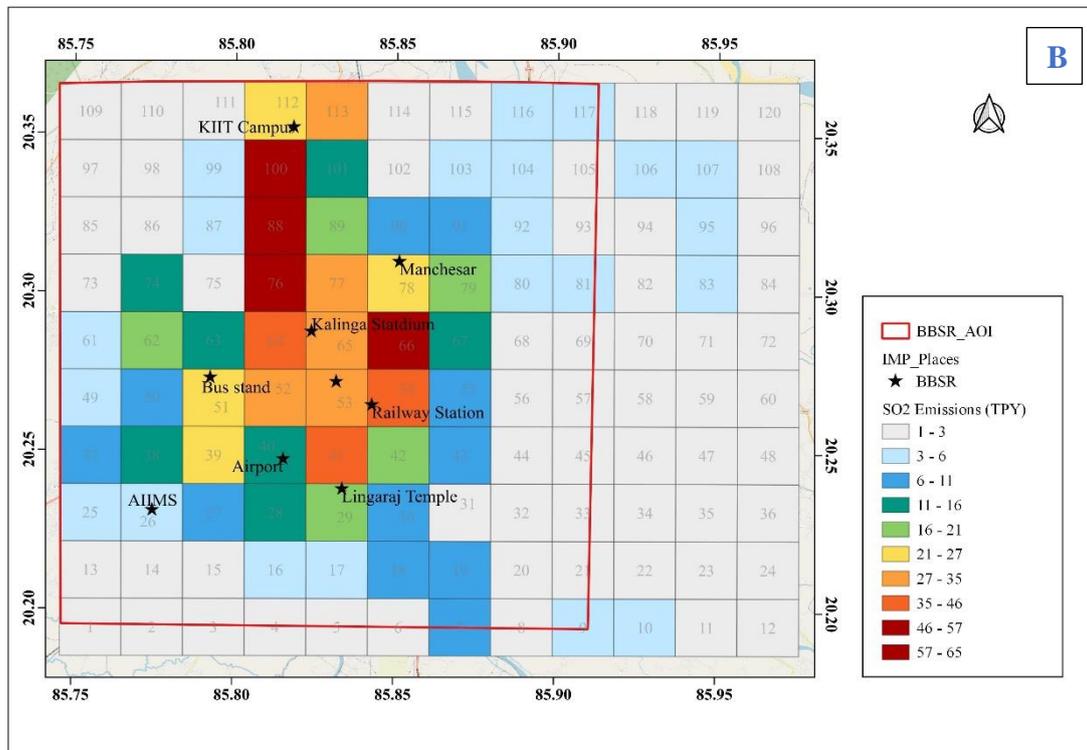
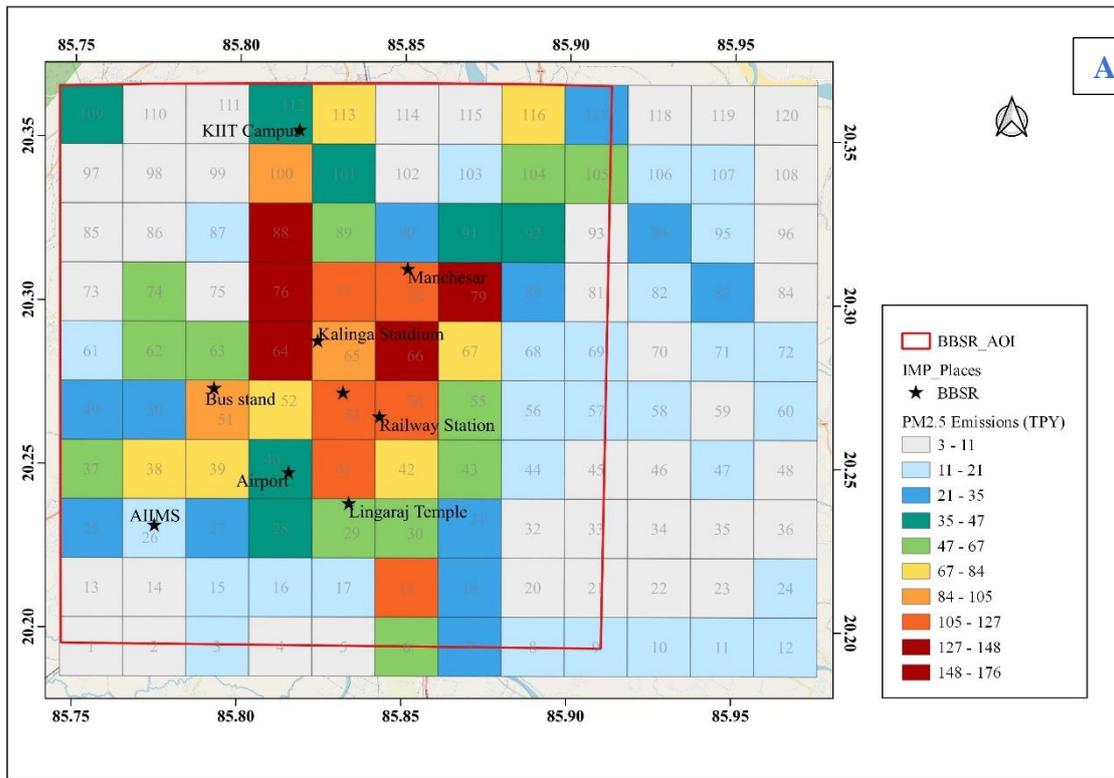


FIGURE ES-5 SPATIAL DISTRIBUTION OF AIR POLLUTANT EMISSIONS A) PM<sub>2.5</sub> AND B) SO<sub>2</sub>(TONNES PER YEAR) IN BHUBANESWAR REGION IN 2022.

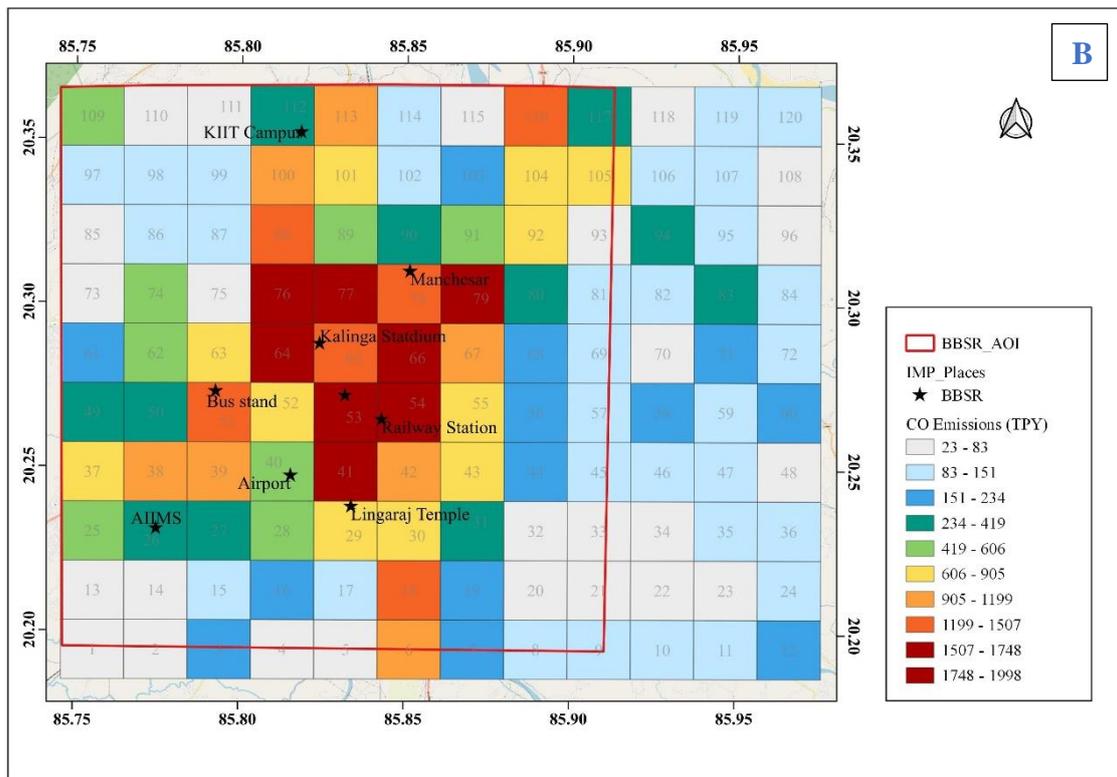
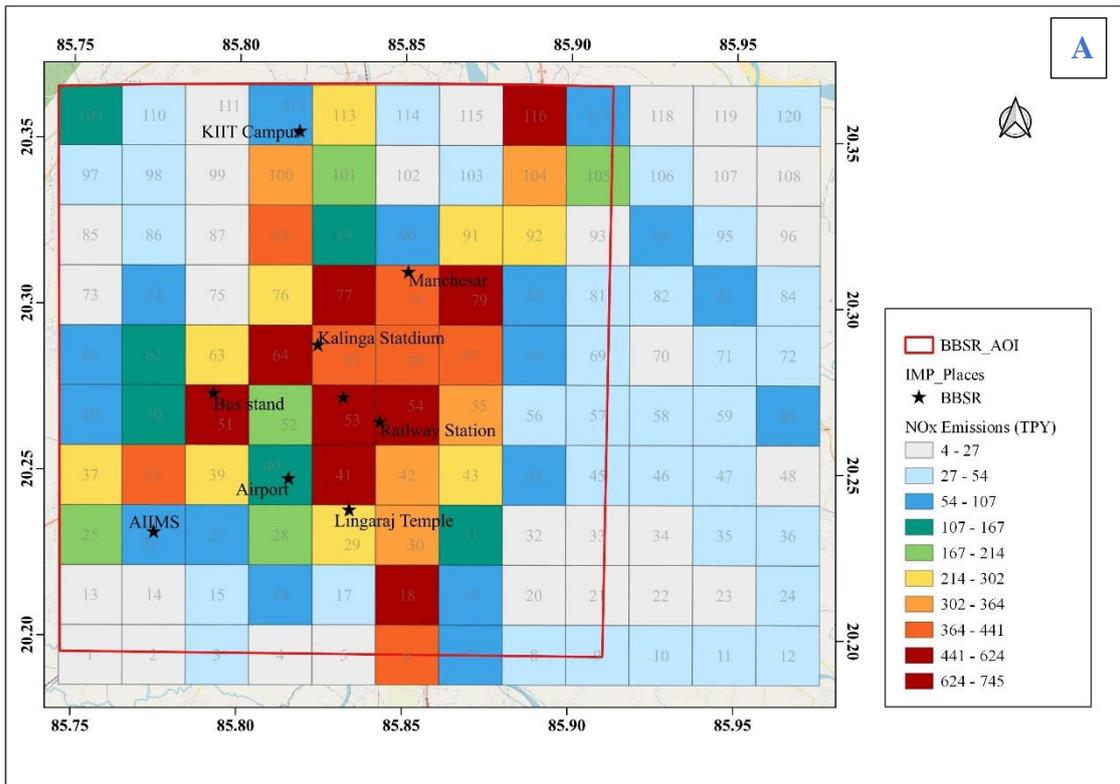


Figure ES-6 Spatial distribution of air pollutant emissions C) NO<sub>2</sub>, D) CO (tonnes per year) in Bhubaneswar region in 2022.

## **Dispersion Modelling**

In this study the AERMOD model is used to estimate the pollutant concentrations under different emission scenarios. Considering the sources and dependent activities in Bhubaneswar and Cuttack region, AERMOD simulations are conducted for the region in a combined manner. AERMOD is configured to consider the local meteorology, emissions and terrain information to simulate the air pollutant concentrations at specified receptors in the study domain. The emissions from different sectors are modelled as area sources having dimensions 2 x 2 km<sup>2</sup>, except the industries and thermal powerplants, crematoria, industrial fugitive dust and brick kilns. The stack emissions from industries, thermal powerplants, crematoria, and FCBTK brick kilns are modelled as point sources. Industrial fugitive dust sources are modelled as area polygon sources while clamp type brick kilns are modelled as volume sources.

The gridded receptors are placed at the vertex of each grid cell used in the emission inventORIZATION, forming a network of 260 gridded receptors (refer Fig. ES-7). Additionally, seven discrete receptors are also configured at ARAI sampling sites locations. The height of each receptor is set to 1.5 m above ground level i.e. mean breathing level for humans. Further, suitable background concentrations are also considered, to reflect the regional-scale contributions from distant sources.

In order to validate the dispersion modelling set-up, the AERMOD simulated average concentrations of pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, and NO<sub>2</sub> are compared against NAMP monthly observations during the modelling period. Based on the analysis, the AERMOD model has been found to estimate the pollutant concentrations in Bhubaneswar-Cuttack region, with a reasonable accuracy. Fig. ES-8 shows the spatial distribution of AERMOD simulated PM<sub>10</sub> and PM<sub>2.5</sub> concentrations during baseline year, respectively.

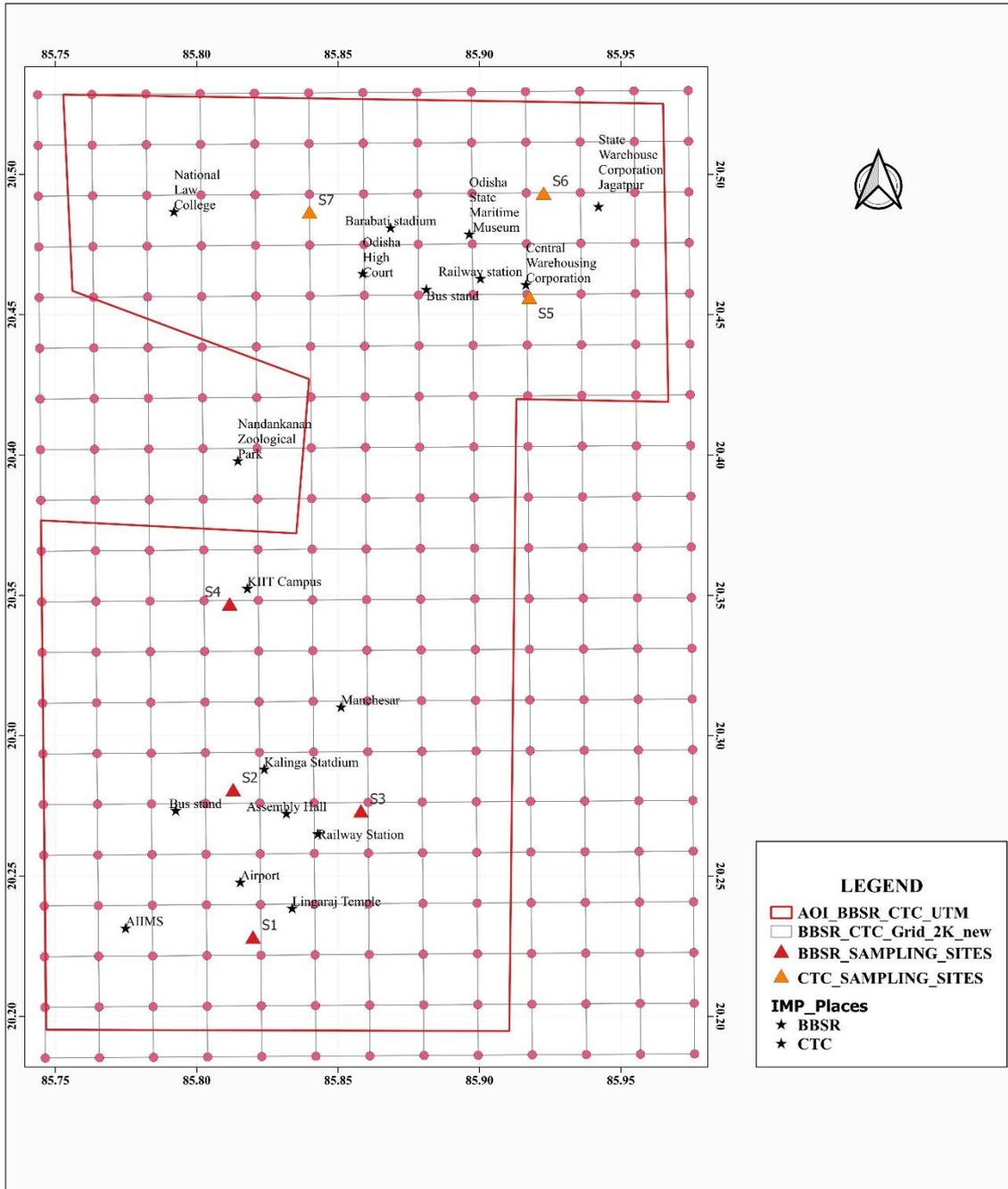


FIGURE ES-7 MAP SHOWING AERMOD MODELLING DOMAIN OVERLAID BY GRIDDED AND DISCRETE RECEPTORS CONFIGURED IN THIS STUDY.

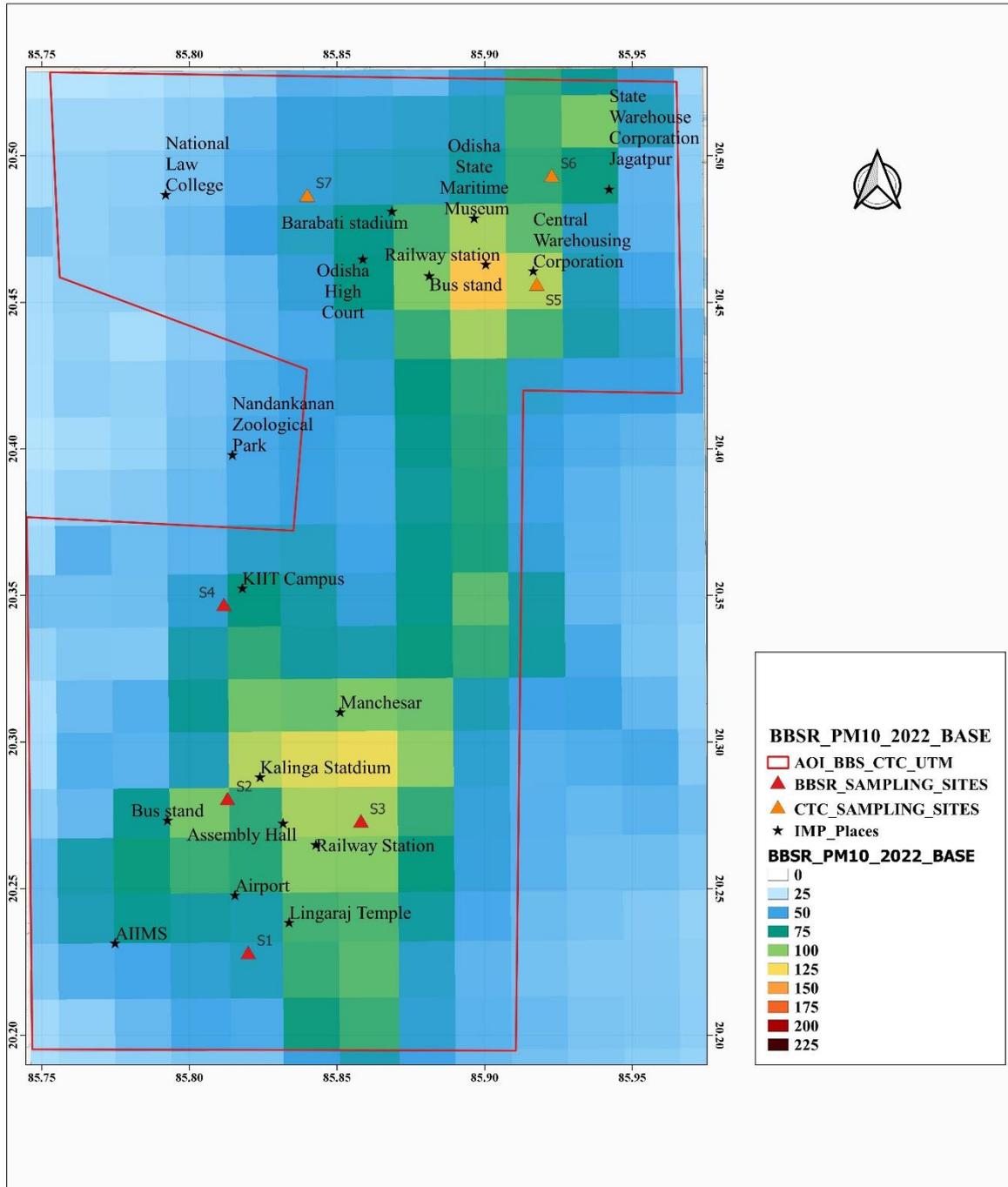


FIGURE ES-8 MAP SHOWING SPATIAL DISTRIBUTION OF **PM<sub>10</sub>** ANNUAL MEAN CONCENTRATIONS ( $\mu\text{G}/\text{M}^3$ ) OVER BHUBANESWAR-CUTTACK REGION FOR YEAR 2022

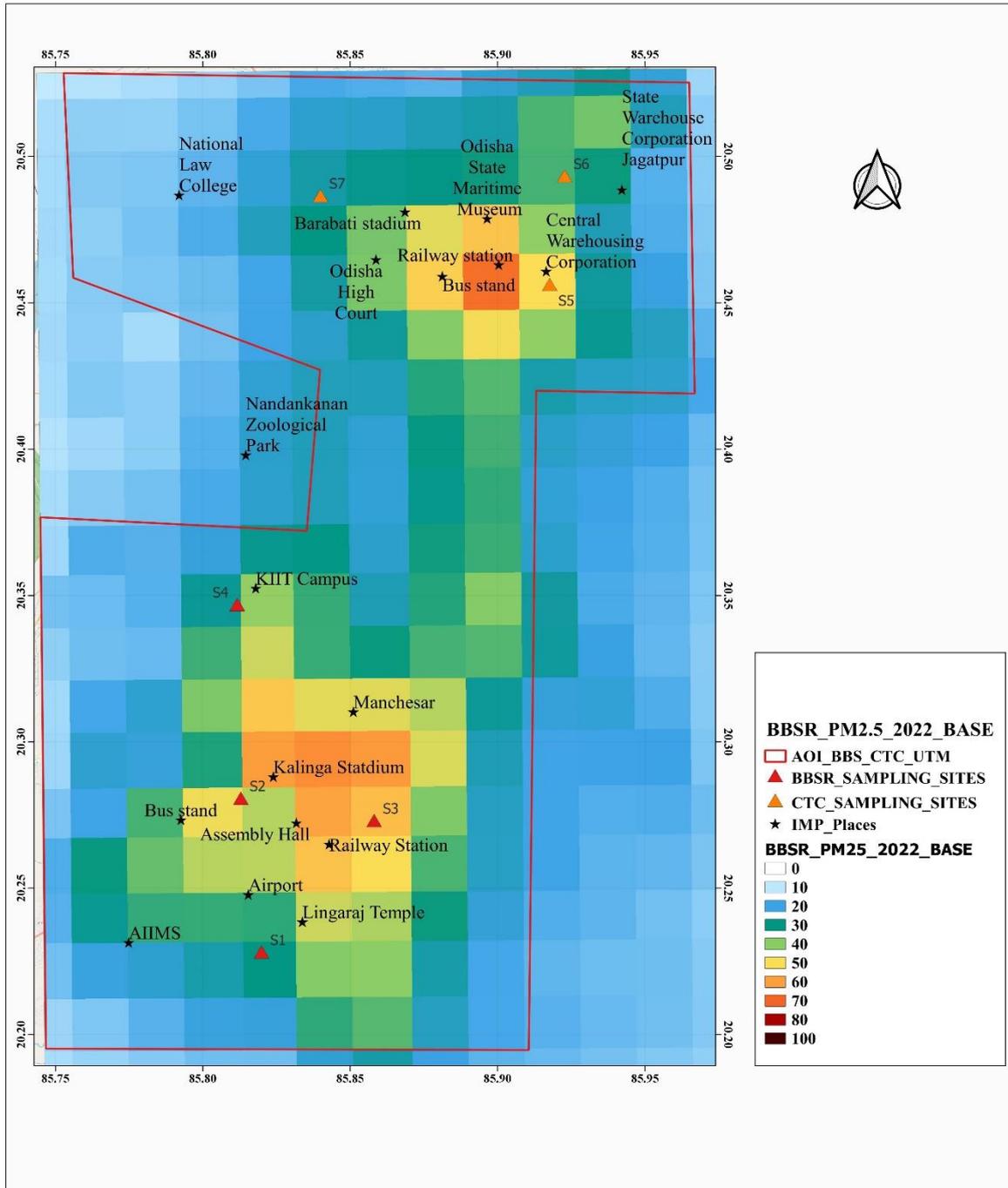


FIGURE ES-9 MAP SHOWING SPATIAL DISTRIBUTION OF  $PM_{2.5}$  ANNUAL MEAN CONCENTRATIONS ( $\mu G/M^3$ ) OVER BHUBANESWAR-CUTTACK REGION FOR YEAR 2022

## **Future projections and air quality benefits**

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 2022. Four hypothetical emission scenarios viz. i) No further control (NFC), ii) Business-as-usual (BAU), iii) Scenario – I (SC-I) and iv) Scenario – II (SC-II); are developed for Bhubaneswar region to include various existing and planned control interventions in each sector. These scenarios can be defined as given below:

- i) **No further control (NFC):** No further control (NFC) scenario assume that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 but the control measures would be similar to present/current levels.
- ii) **Business-as-usual (BAU):** Business-as-usual (BAU) scenarios consider that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 while the already planned control measures would be implemented.
- iii) **Scenario – I (SC-I):** Scenario – I (SC-I) consider that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 while the planned control measures would be implemented more aggressively compared to BAU scenarios.
- iv) **Scenario – II (SC-II):** Scenario – II (SC-II) consider that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 while the planned control measures would be implemented to the highest aggressive levels, possible.

These scenarios consider changes in technology and fuels which mainly include: faster EV adoption, implementation of BS-VI, increase in penetration of natural gas-based vehicles, roll-out of ethanol blended gasoline fuel (E20), reduction in silt loading on road surfaces, operational mass transit system (MRTS), improvement in NMT & public transport, usage of clean fuel for cooking, improved waste collection efficiency, continuous supply of grid electricity, adoption of Zig-zag type brick kilns and various other control measures. The four emission scenarios investigated in the study can be further categorized as mid-term (2027) and long term (2032). The details on sector-wise considerations and assumptions are provided in Chapter 5 of the report. Table ES-3 summarizes the estimated emissions (tonnes per year) of selected pollutants under four scenarios in Bhubaneswar region for years 2022, 2027 and 2032.

TABLE ES-3 ESTIMATED EMISSIONS (TONNES PER YEAR) OF SELECTED POLLUTANTS UNDER  
FOUR SCENARIOS IN BHUBANESWAR REGION FOR YEARS 2021, 2027 AND 2032

Year	Scenario	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>x</sub>	CO
2021	BASE	7,714	4,359	1,125	17,142	54,698
2027	NFC	10,387	5,527	1,508	20,415	68,864
	BAU	9,427	5,130	1,522	21,180	66,371
	SC_I	8,036	4,372	1,122	19,441	61,299
	SC_II	6,581	3,666	929	17,517	56,577
2032	NFC	13,542	6,596	1,864	21,055	83,474
	BAU	10,347	5,395	1,762	21,674	76,948
	SC_I	7,567	3,966	1,274	17,903	68,211
	SC_II	4,382	2,599	721	15,186	59,375

The NFC scenario projections in Bhubaneswar region indicate a potential increase in PM<sub>10</sub> emissions to 10,387 tonnes per year in 2027 i.e. an increase of 34.6% w.r.t. baseline year 2022 and to 13,542 tonnes per year in 2032 i.e. an increase of 75.5% w.r.t. baseline year 2022. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to reach to 5,527 (26.8%) and 6,596 tonnes per year (i.e. 51.3%) in 2027 and 2032, respectively. The BAU projections in Bhubaneswar indicate a potential decrease of PM<sub>10</sub> emissions to 9,427 tonnes per year in 2027 i.e. a decrease of 9.2 % w.r.t. NFC\_2027 and to 10,347 tonnes per year in 2032 i.e. a decrease of 23.6% w.r.t. NFC 2032. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to decrease to 5,130 (-7.2%) and 5,395 tonnes per year (i.e. -18.2%) in 2027 and 2032, respectively.

The SC-I projections in Bhubaneswar region indicate a potential decrease of PM<sub>10</sub> emissions to 8,036 tonnes per year in 2027 i.e. a decrease of 22.6% w.r.t. NFC 2027 and to 7,567 tonnes per year in 2032 i.e. a decrease of 44.1% w.r.t. NFC 2032. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to decrease to 4,372 (-20.9%) and 7,567 tonnes per year (i.e. -39.9%) in 2027 and 2032, respectively. The SC-II projections in Bhubaneswar region indicate a potential decrease of PM<sub>10</sub> emissions to 6581 tonnes per year in 2027 i.e. a decrease of 36.6% w.r.t. NFC 2027 and to 4382 tonnes per year in 2032 i.e. a decrease of 67.6% w.r.t. NFC 2032. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to decrease to 3666 (i.e. -33.7%) and 2599 tonnes per year (i.e. -60.6%) in 2027 and 2032, respectively.

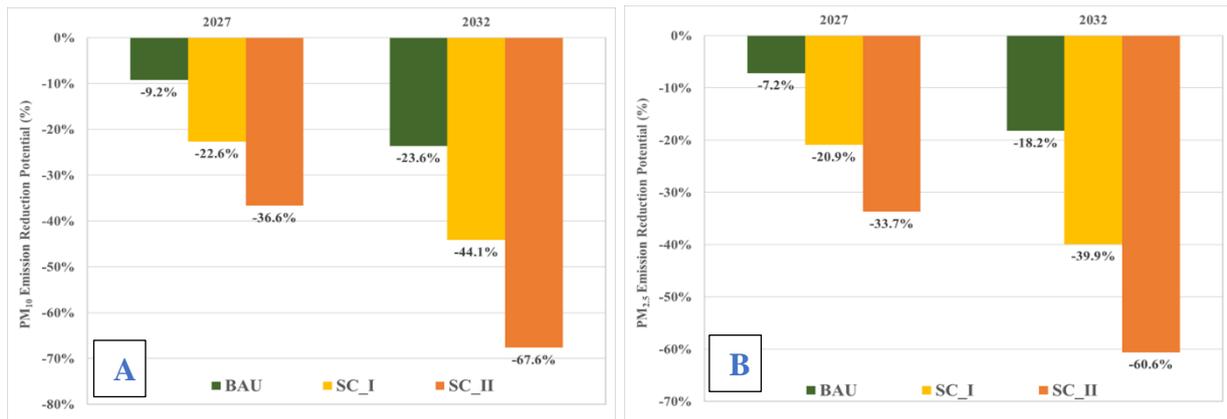


FIGURE ES-10 ESTIMATED **PM<sub>10</sub>** (A) AND **PM<sub>2.5</sub>** (B) EMISSION REDUCTION POTENTIAL (%) W.R.T. NFC IN THREE SCENARIOS (BAU, SC-I, AND SC-II OF 2027 AND 2032)

Air quality benefits of four designed scenarios were assessed for years 2027 and 2032 using AERMOD modelled annual mean pollutant concentrations in Bhubaneswar-Cuttack region. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2027 and 2032 due to proposed changes in technology and fuels of vehicles such as EV adoption, increased penetration of BS-VI vehicles, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, NMT & improvement in public transport, introduction of mass rapid transit system (MRTS), increasing use of clean fuel for cooking, improved waste collection efficiency, adoption of Zig-zag type brick kilns and various other control strategies considered in different scenarios.

With implementation of control measures considered in different scenarios, an estimated reduction of 6.7%, 14.3%, and 22.8% in 2027 and 16.3%, 30.2%, and 46.3% in 2032, could be achieved in ambient PM<sub>10</sub> concentrations for BAU, SC-I and SC-II scenarios, respectively. In case of PM<sub>2.5</sub>, with implementation of control measures considered in different scenarios, an estimated reduction of 6.3%, 14.4%, and 22.4% in 2027 and 15.0%, 28.7%, and 43.4% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

This study also assessed location -specific air quality benefits due to implementation of different scenarios in 2027 and 2032. Four representative locations, i.e. ARAI sampling locations, were selected to understand the impact of control measures on air quality. Tables ES-4 presents the percentage change in air pollutants annual mean concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at OSPCB Head Office, Nayapalli site in Bhubaneswar region.

TABLE ES-4 PERCENTAGE CHANGE IN PREDICTED AMBIENT AIR QUALITY CONCENTRATIONS,  
W.R.T. CORRESPONDING NFC SCENARIOS IN 2027 AND 2032 AT OSPCB HEAD OFFICE,  
NAYAPALLI (S2) LOCATION

Year/Scenario	2027			2032		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM <sub>10</sub>	-7.9%	-18.1%	-28.4%	-20.9%	-36.4%	-55.4%
PM <sub>2.5</sub>	-6.9%	-17.2%	-26.5%	-17.3%	-32.6%	-49.5%
SO <sub>2</sub>	-1.6%	-21.6%	-28.3%	-9.5%	-24.7%	-45.2%
NO <sub>2</sub>	-0.4%	-2.3%	-4.7%	-2.3%	-5.8%	-10.0%
CO	-3.0%	-8.2%	-12.9%	-6.5%	-13.7%	-21.8%

The air quality benefits are also translated to improvement in Air quality index (AQI). AQI is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (Ott, 1978). It is important to note that, the AQI values are calculated using the AERMOD estimated pollutant concentrations, only. The air quality situation can gradually improve with implementation of proposed scenarios. The combined proportion of Good and Satisfactory AQI classes are estimated to be substantially higher compared to the corresponding do-nothing or NFC scenario. For example, the combined proportion of Good and Satisfactory AQI classes in NFC is 74% and 60% in 2027 and 2032, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 79% and 75% in 2027 and 2032, respectively under BAU scenario, to 89% and 91% in 2027 and 2032, respectively under SC-I, to 95% and 100% in 2027 and 2032, respectively under SC-II scenario.

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Bhubaneswar region as well. These findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level PM concentrations by 40% by the year 2027, as compared to 2017 i.e. base year.

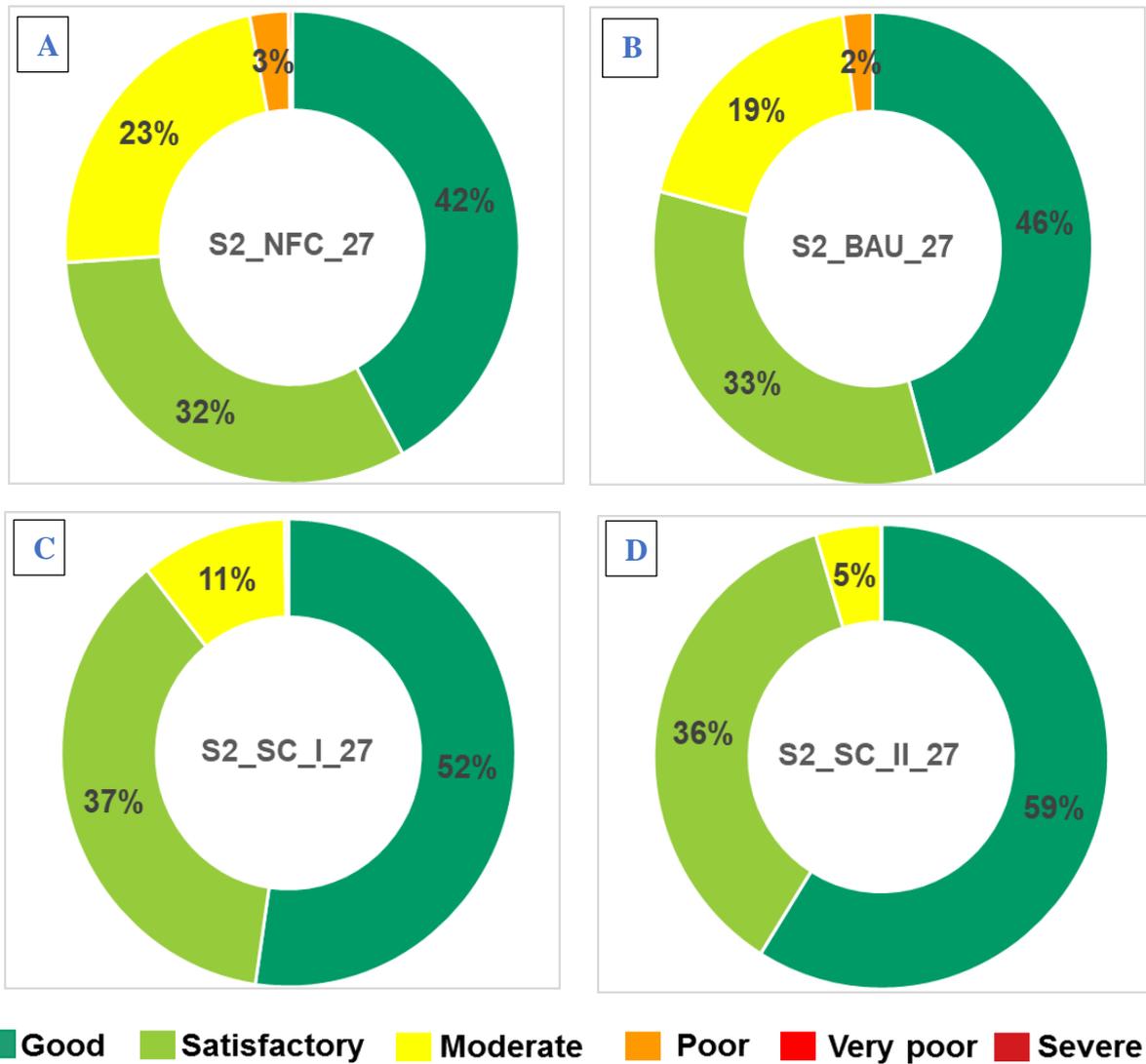


FIGURE ES-11 DISTRIBUTION OF SIX AQI CATEGORIES AT *OSPCB HEAD OFFICE, NAYAPALLI (S2)* IN BHUBANESWAR REGION FOR FOUR SCENARIOS I.E. NFC (A), BAU (B), SC-I (C) AND SC-II (D) IN YEAR 2027

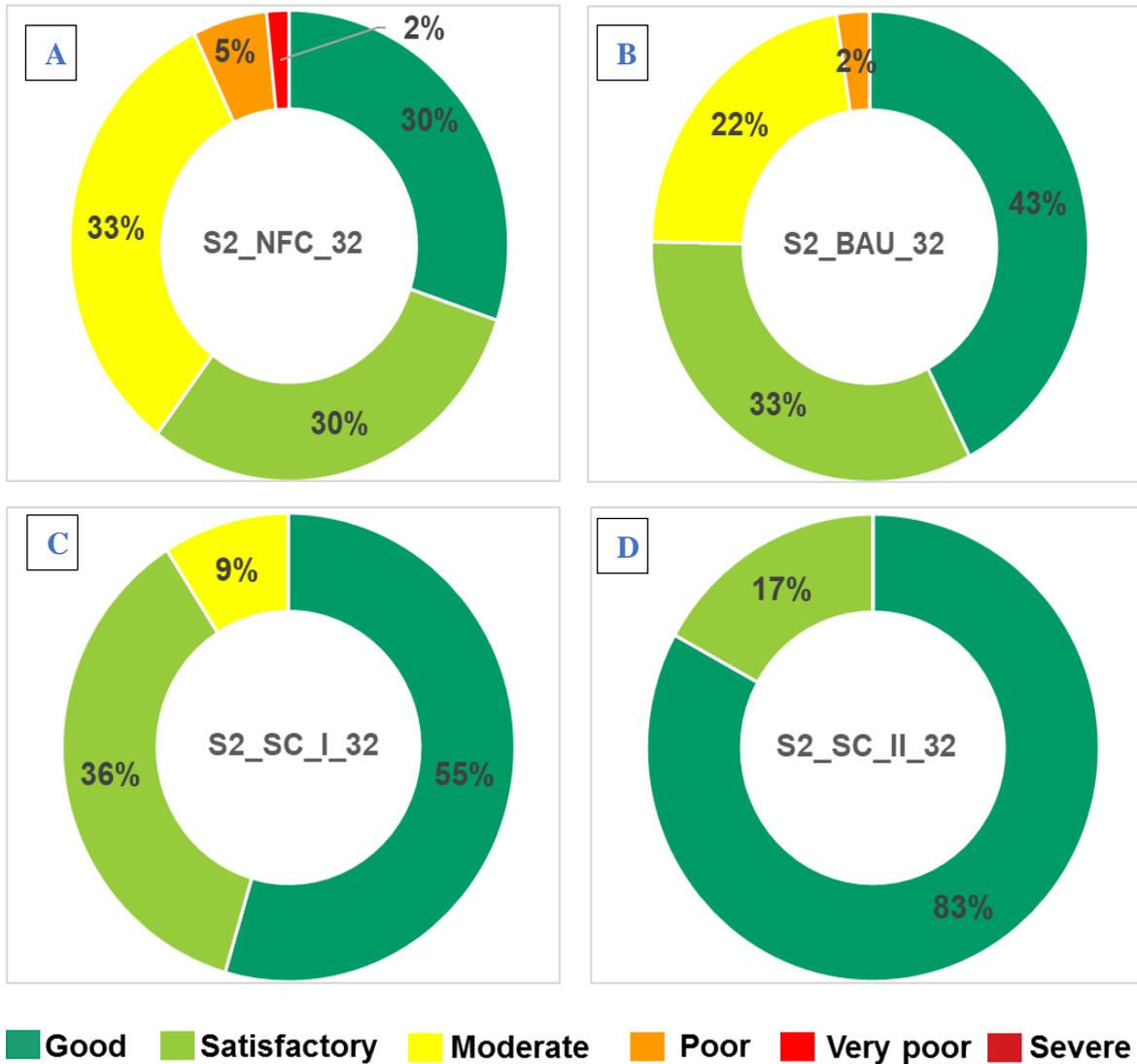


FIGURE ES-12 DISTRIBUTION OF SIX AQI CATEGORIES AT OSPCB HEAD OFFICE, NAYAPALLI (S2) IN BHUBANESWAR FOR FOUR SCENARIOS I.E. NFC (A), BAU (B), SC-I (C) AND SC-II (D) IN YEAR 2032

## Clean Air Action Plan

Table ES-5 presents the proposed air quality action plan for Bhubaneswar region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

TABLE ES-5 PROPOSED AIR QUALITY ACTION PLAN FOR BHUBANESWAR REGION

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Transport	<b>A) Management</b>		
	Congestion Management: Identify the hotspot locations of traffic congestion. Introduce traffic actuated signals at such locations. Consider the one-way routes during peak hours at these locations. Also, regulate eateries along the kerbside, especially small ones to avoid traffic congestions.	RTO	Immediate
	Parking Policy: Formulate vehicle parking policy and ensure its effective implementation. Provide parallel parking system along the major roads of the town. Enforce strict action and penalty for vehicles parked in non-parking areas.	Municipal Corporation / RTO	6 months
	Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses), implementation of plan for metro and increase coverage as per plan.	Municipal Corporation	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	Municipal Corporation	1 -2 years
	Declare NO-vehicle zones in hot-spots, university / school premises.	Municipal Corporation / University / School	6 months
	Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO	Immediate
	Examine existing framework for removing broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.	Municipal Corporation/ Local Govt. Body	6 months

Sector	Control Actions	Responsible Agency / Authority	Time Frame
<b>B) Technology</b>	Improve and strengthen PUC program. (SMS based system to alerts, Linking of PUC centres with remote server and elimination of manual intervention in PUC testing, Fitness and calibration audits of PUC centres adopted with defined team for verification, Integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, Linking of PUC certificates with annual vehicle insurance, etc.)	RTO	1 year
	Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Oil Companies/ GAIL / State Government	3 years
	The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	Municipal Corporation/ Local Govt. Body, Government Offices	3 years
	Encouraging EV adoption for personal and commercial vehicles through incentivization or tax relaxation.	State Government, RTO	3 years
<b>Road Dust</b>	End-to-end paving of roads along with black-topping and maintaining potholes free roads.	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	Municipal Corporation/ Local Govt. Body	6 months
	All the canals/nallah's side roads should be concrete / brick lined.	Municipal Corporation/ Local Govt. Body	1 year
	Regular cleaning of roads and water spraying to suppress the dust. Remove road dust/silt regularly by using mechanical sweepers.	Municipal Corporation/ Local Govt. Body	Immediate / Continuous

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Identify road stretches with high dust generation and use Foggers to suppress the dust.	Municipal Corporation/ Local Govt. Body	6 months
	Greening of traffic corridors, open areas, gardens, community places, schools and housing societies	Municipal Corporation/ Local Govt. Body	1 year
<b>Industries</b>	All potential industries to be implemented with Continuous Emission Monitoring System (CEMS).  Ensure regular calibration and working of this system and its online reporting is required.	OSPCB	1 year
	Assess the number of industrial units that are non-compliant and prepare unit/plant wise action plan for time bound compliance.	OSPCB	Immediate and Continuous
	Intensive polluting industries to be restricted from operations within urban zone.  Restriction of any new red category industry to open within urban zone.	OSPCB	Immediate
	Strict compliance to be followed on industrial open waste burning.	OSPCB	Immediate
	Control of Fugitive Emissions:  <ul style="list-style-type: none"> <li>• Use of hoods and enclosure for all process equipment,</li> <li>• Scrap management programme for the prevention or minimization of waste and other feed materials.</li> <li>• Use of covered or enclosed conveyors and transfer points</li> <li>• Enclosures for emission controls of the charging and tapping operations.</li> <li>• Minimising the number of flanges by welding piping connections wherever possible and using appropriate sealing for flanges and valves</li> <li>• Use of larger oven chambers and regulation of pressure within oven chambers</li> </ul>	OSPCB	Immediate
	Adoption of Cleaner Fuels:  <ul style="list-style-type: none"> <li>• Cleaner fuel implementation to be encouraged and incentivized.</li> </ul>	OSPCB	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	<ul style="list-style-type: none"> <li>Discourage the fuels with high sulphur content.</li> <li>A favourable taxation and pricing policy for mass adoption.</li> </ul>		
	Ensuring installation/Up-gradation and operation of air pollution control devices in industries	OSPCB	6 months
	Disposal of all non-hazardous wastes into the designated dumping sites	OSPCB	Continuous
	Industry shall prepare plant wise inventory of vents and ensure that it is routed to vapour recovery system followed by flare system, wherever applicable.	OSPCB	6 months
	Regeneration frequency of Adsorption / absorption system / Activated carbon bed should be clearly defined as per the trend data of previous cycles and should be documented.	OSPCB	6 months
	Industry should include a special training module regarding “fugitive emissions and its health impacts on individual and surrounding communities” for its staff, operating personnel & Drivers to spread awareness about risk/hazard associated with spills and leaks of various chemicals.	OSPCB	Continuous
	Bank guarantee should be taken for the compliance of conditions imposed in CTO/CTE for control of Environmental Pollution from industries.	OSPCB	6 months
	Industrial units to install water spraying system of internal roads and washing of tyres of vehicles	OSPCB	6 months
	Development of mobile facility/van for continuous ambient air quality monitoring for different localities.	OSPCB	6 months
<b>Open Waste Burning</b>	Improving door to door waste collection efficiency to 100%.	Municipal Corporation/ Local Govt. Body	1 year
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	Municipal Corporation/ Local Govt. Body	Immediate
	Non-recyclable waste with a calorific value of 1,500 kcal or more must not be disposed of into landfills and must be used solely to generate energy	OSPCB, Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	Municipal Corporation/ Local Govt. Body	Immediate / Continuous

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Encouraging the reduce, recycle and reuse policy for waste in city	Municipal Corporation/ Local Govt. Body / State Government	Immediate / Continuous
	Organic waste conversion (OWC) units can be installed in the city at a decentralized scale especially in more prominent societies and colonies based on the MSW characteristics of the area.	Municipal Corporation/ Local Govt. Body	1 year
	Effective management of landfill sites through increasing the recycling rate, installing waste to energy conversion plants, restricting illegal waste dumping, proper disposal of hazardous waste, as per Hazardous waste management rule 2016, to prevent greenhouse gas emissions from site	Municipal Corporation/ Local Govt. Body	1 year
	Reduce the VKT of waste collection vehicles with route optimisation technique.	Municipal Corporation/ Local Govt. Body	6 months
<b>Construction</b>	Adoption of Good Construction Practices (GCP) to minimize the waste generation. Promote recycling of materials. Encourage the use of environmentally friendly material. Ensure compliance check for GCP regularly	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate
	Strict enforcement of CPCB guidelines for construction activity such as use of green screens, side covering of digging sites, etc.	Municipal Corporation/ Local Govt. Body / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	Municipal Corporation/ Local Govt. Body	Immediate
	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	3 months

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Develop and implement dust control measures such as site covering, fugitive emission control, installing air pollution controlling devices for all types of construction activities i.e. buildings and infrastructure.	Municipal Corporation/ Local Govt. Body	1 year
	C&D waste should be sent to construction and demolition processing facility only. Strict action against non-compliance of the same on any individual or developers.	Municipal Corporation/ Local Govt. Body	Immediate
	Mandatory use of RMC plants at large construction sites and preparation of guidelines for dust control measures for operation of RMC plants.	Municipal Corporation/ Local Govt. Body / OSPCB	1 Year
DG sets	Ensure uninterrupted electric supply to avoid the use of DG sets, especially in commercial and industrial zones.	State Electricity Board	1 Year
	Curtail use of DG Sets in social events by providing temporary electric connections	Municipal Corporation/ Local Govt. Body / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	Municipal Corporation/ Local Govt. Body	6 months
	Develop the city into a Renewable Energy Hub with a focus on creation of RE Equipment Manufacturing Eco-system as per Odisha Renewable energy policy	Municipal Corporation/ Local Govt. Body / State Government	5 years
	Leverage rooftop solar programme to reduce dependence on DG sets.	Municipal Corporation/ Local Govt. Body	1 year
	Installation of Retrofitted Emission Control Devices (RECD) to diesel generators as per CPCB guidelines	OSPCB	1 year
Residential	Ensure easy availability of affordable cleaner cooking fuels (LPG/ PNG/biogas) for all to achieve 100% LPG adoption.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP/BP, etc.)	1-3 years
	Expanding coverage of LPG under Pradhan Mantri Ujjwala Yojana (PMUY).	State / Central Government	1-2 years
	Introduce schemes for providing subsidized LPG connections as well as providing means of finance to small tea vendors/hawkers who are using kerosene stoves in order to reduce emissions from burning of kerosene	State / Central Government	1-2 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Introduction of improved <i>Chullahs</i> (low emission <i>Chullahs</i> ) in rural areas	Municipal Corporation/ Local Govt. Body, NGOs	1 year
	Encouraging use of electricity for domestic cooking. (for example: Induction cooktops)	Department of Food, Civil Supplies and Consumer Affairs	2 year
	Provide centralized solar based hot water in slum areas to avoid solid fuel usage for water heating purposes	Municipal Corporation/ Local Govt. Body	1 year
Hotel, restaurant and bakeries	Coal and wood-based cooking in restaurants to be shifted to electricity and LPG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1-2 years
	Promoting mini LPG cylinders to small open eateries.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
Brick kilns	Ensure the compliance checking routinely. Provide design specifications for improved kilns.	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate
	Enforce restrictions for the operations of brick kilns in urban zone. Zig-Zag technology to be encouraged and promoted. Ensure the mass adoption of Zig-Zag or improved technology	Municipal Corporation/ Local Govt. Body / OSPCB	1-3 years
	Closure of unauthorized brick kilns, if any.	OSPCB	Immediate
Crematoria	Convert all existing traditional crematoria (wood based) to electric. Installing new electric crematoria as per requirement.	Municipal Corporation/ Local Govt. Body	1 year
Public Awareness	Launch Public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicle, lane discipline, etc.	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
	Encourage the use of public transport for daily commute.	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
	Education program to create awareness among citizens through various mass media tools, such as local newspapers, local news channels on TV or radio, street plays, social media platforms, citizen engagement events, recording announcements through waste collection vehicle, organizing awareness seminars at the community level	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	Municipal Corporation/ Local Govt. Body	1 year
CAAQMS	Increase the number of air quality monitoring stations, as per applicable Govt. guidelines.	OSPCB	1 -2 year

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## **Chapter 1: Introduction**

### **1.1. Background**

Air pollution has become a serious problem in recent years with PM<sub>2.5</sub> i.e. particles with aerodynamic diameter less than or equal to 2.5 µm, accounting for about 4.9 million deaths worldwide and ~1.2 million deaths in India in the year 2017 (HEI, 2019) and it is considered as a major challenge for air pollution and health regulatory agencies around the world. Similarly, PM<sub>10</sub> i.e. particles with aerodynamic diameter less than or equal to 10 µm, has also been shown to affect health in the short-term while long-term effects are yet to be confirmed (Katzman et al., 2010). The particulate matter is considered dangerous, primarily due to its fine size; but its chemical composition makes it even more hazardous for humans (Pope III et al., 2002, 2006). Particulate matter often consists of carbon, sulfate and nitrate compounds, but also may include other substances such as heavy Elements (WB and IHME, 2016), mineral dust and sea salt. The chemical composition of PM offers valuable information to identify the contributions of specific sources and to understand aerosol properties and processes that could affect health, climate, and atmospheric conditions.

The Central Pollution Control Board (CPCB), New Delhi has identified 131 cities in India where the prescribed annual National Ambient Air Quality Standards (NAAQS) are violated. Considering the health impacts associated with PM, the Indian planning and regulatory agencies have also aligned their roadmap towards effectively addressing the PM<sub>2.5</sub> pollution. India's National Clean Air Program (NCAP) launched by Ministry of Environment, Forest and Climate Change (MoEFCC) in 2019 aims to reduce the national level PM<sub>2.5</sub> and PM<sub>10</sub> concentrations by 20-30% by year 2024, taking 2017 as the base year for the comparison of concentration. The earlier/original targets were recently revised to achieve reductions up to 40% of PM<sub>10</sub> concentrations by 2025-26 (MoEFCC, 2023). The overall objective of the India's NCAP is comprehensive mitigation actions for prevention, control and abatement of air pollution besides augmenting the air quality monitoring network across the country and strengthening the awareness and capacity building activities (MoEFCC, 2020).

NCAP has identified 16 key components in order to achieve national level PM<sub>2.5</sub> and PM<sub>10</sub> targets. It is proposed to extend emission inventory and source apportionment of particulate matter to non-attainment cities in India and plan actions for controlling and reducing air pollution based on such scientific studies. A cost-effective approach for improving air quality in such cities involve (i) identification of emission sources; (ii) assessment of extent of

contribution of these sources on ambient environment; (iii) prioritizing the sources that need to be tackled; (iv) evaluating various options for controlling the sources with regard to feasibility and economic viability; and (v) formulation and implementation of most appropriate action plans (MoEFCC, 2020).



*Figure 1 Key components of India's National Clean Air Program (NCAP; Source: MoEFCC, 2020)*

Seven cities including Angul, Balasore, Bhubaneswar, Cuttack, Rourkela, Talcher, Kalinga Nagar in Odisha state have also been identified by CPCB in the above list due to routine violation of NAAQS mainly in terms of PM<sub>10</sub>. State Pollution Control Board, Odisha (OSPCB) has entrusted The Automotive Research Association of India (ARAI), Pune to carry out a detailed study on “Emission Inventory and Source Apportionment Study of Bhubaneswar Region in Odisha”.

## 1.2. Brief Description of the study area

Bhubaneswar, the capital city of the Indian state of Odisha, is renowned for its rich cultural heritage, vibrant temples, and burgeoning modern infrastructure. Known as the "Temple City of India," Bhubaneswar boasts of ancient temples like the Lingaraj Temple and the Mukteshwar Temple, showcasing exquisite Kalinga architecture. The city blends its historical significance with modern developments, including IT parks, educational institutions like IIT Bhubaneswar, and a growing economy. Its green spaces, cultural festivals, and traditional Odia cuisine add to its charm, making Bhubaneswar a unique destination that harmoniously merges tradition with contemporary life.

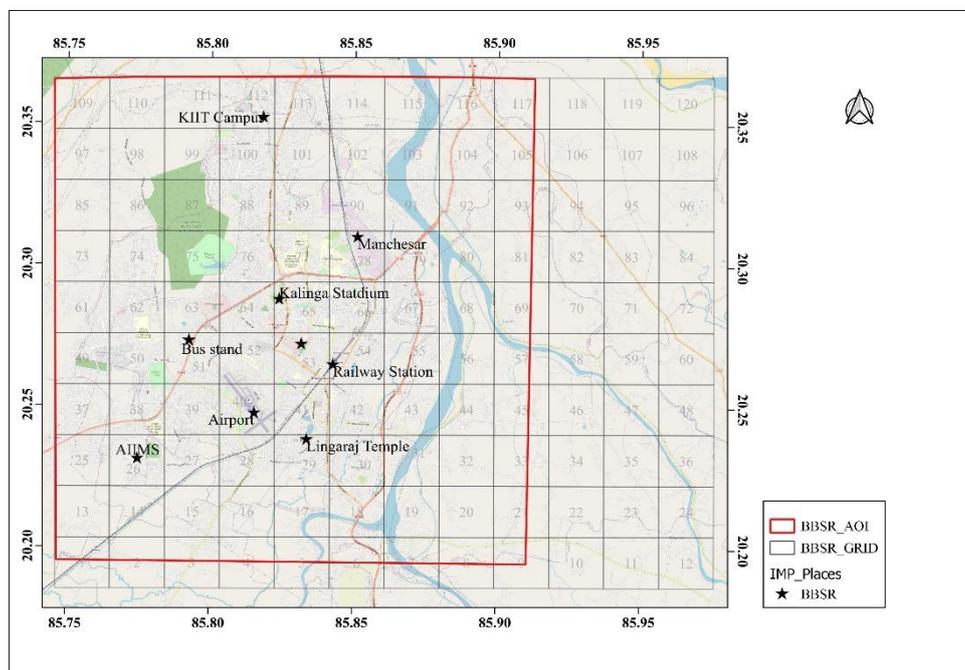


Figure 2 Map showing study area i.e. Bhubaneswar region

### 1.2.1. Geography

Bhubaneswar, the capital of Odisha state, is also referred to as the temple city of India due to its large number of religious temples. The city is located in Khordha district of Odisha at an average elevation of about 45 m above mean sea level. The study area of Bhubaneswar lies in between geographic coordinates from 85.74647, 20.18510, to 85.97458, 20.42149. A river called Kuakhai which is distributary of Mahanadi river flows through the centre of the study area. It is important to note that, the study area for this study extends beyond the municipal limits of Bhubaneswar and covers an area of 624 km<sup>2</sup>. Fig. 2, shows the study area divided into grids of size 2 x 2 km<sup>2</sup> for the emission inventory purpose.

### 1.2.2. Weather and Climate

Bhubaneswar exhibits a tropical climate and temperatures usually range from 11 to 45 °C. The city receives abundant rainfall during Southwest monsoon (June – September). The highest and lowest temperatures are generally observed in the months of May and January, respectively. Bhubaneswar receives an annual average rainfall of about ~1,657 mm, with highest rainfall in the month of August.

### 1.2.3. Demography

According to Census of India 2011, the total population of Bhubaneswar municipal corporation was 8,40,834. As discussed previously, the study area extends beyond municipal limits and geo-located population details are not available for this region. Hence, first we derived the gridded population of the study area for year 2011, using population dataset prepared by Balk et al. (2020). The estimated gridded population for year 2022 is 12,64,335 based on several factors such as current and proposed land use, land cover, population density, growth directions, and scope for future development. Fig. 3 shows the gridded population map of the study area for year 2022.

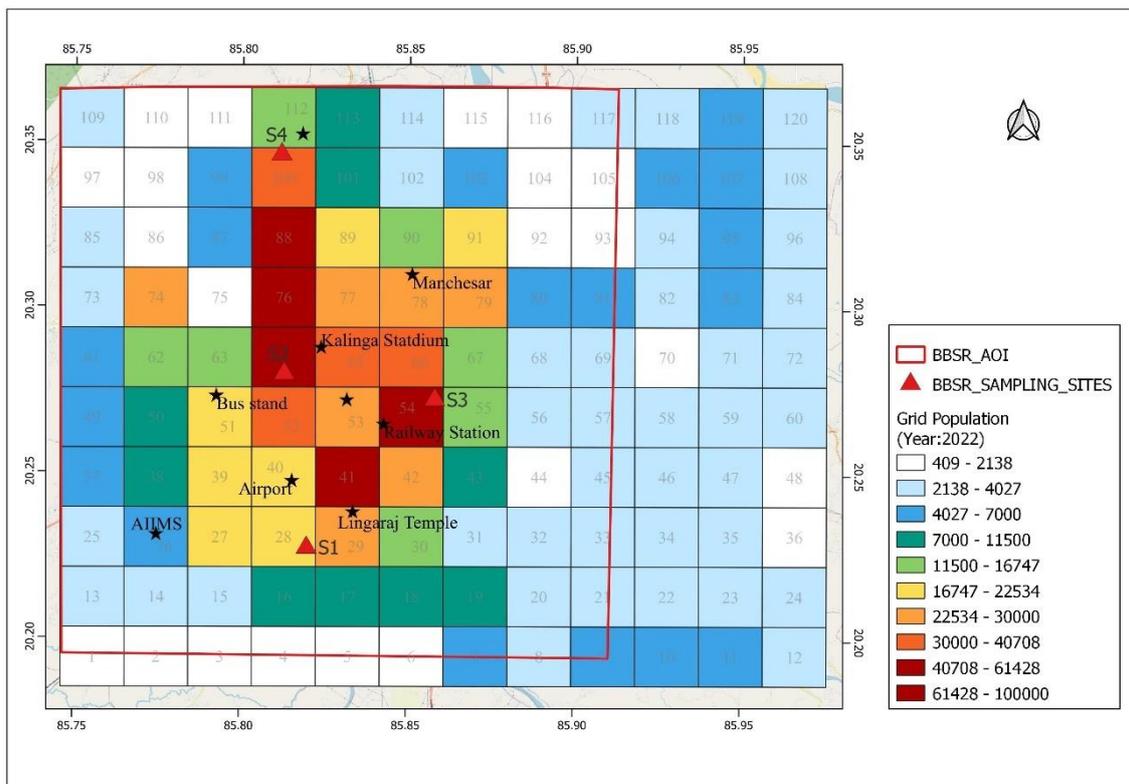


Figure 3: The estimated gridded population of the study area for year 2022.

### **1.3. Objectives of the Project**

The main aim of this study is to identify and characterize various emission sources in Bhubaneswar region in Odisha and help the regulatory agencies in prioritizing the actions for improving the air quality. The objectives of the study are:

- i) To carry out particulate matter (PM<sub>10</sub> & PM<sub>2.5</sub>) source apportionment using receptor modelling approach for Bhubaneswar region.
- ii) To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Bhubaneswar region.

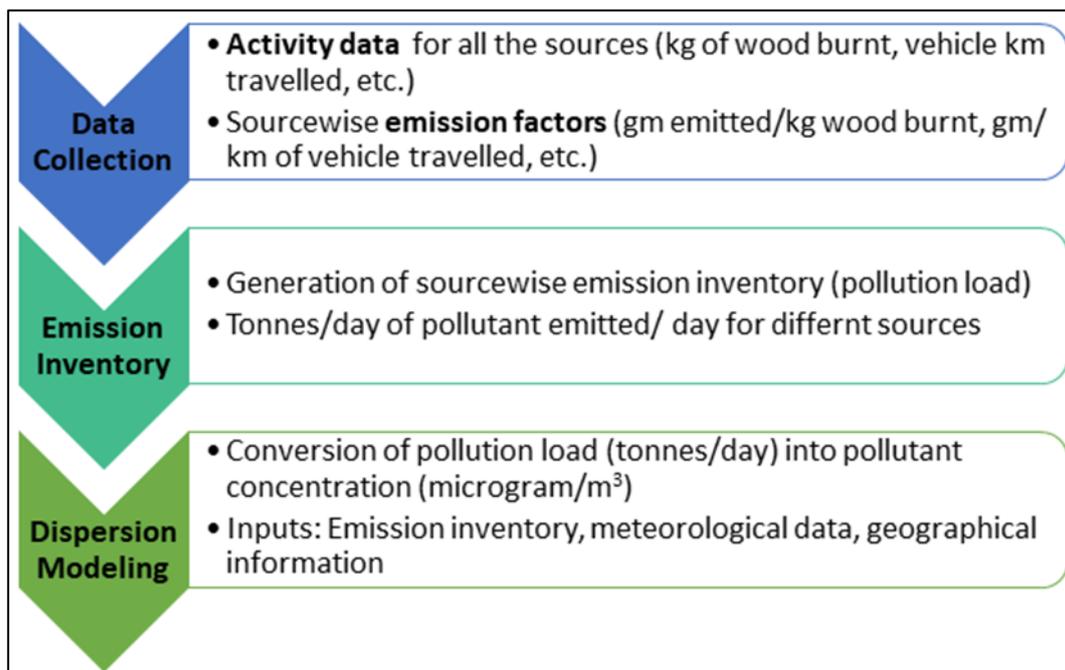
### **1.4. Scope of Work**

- 1.1. Sampling of Particulate Matter (PM<sub>10</sub> & PM<sub>2.5</sub>) using speciation samplers at identified sites (4 locations in Bhubaneswar region). Sampling (24 hrs) for minimum 15 days at each location in 2 critical seasons i.e. winter and summer. Additionally, sampling and analysis for SO<sub>2</sub>, NO<sub>2</sub>, Benzene, Toulene, Ethyl Benzene and Xylene identified locations during winter season only.
- 1.2. Analysis of collected Particulate Matter (PM<sub>10</sub> & PM<sub>2.5</sub>) samples for ions, elements, carbon fractions (organic and elemental carbon) and molecular markers (PAHs, alkanes, hopanes).
- 1.3. To carry out PM<sub>10</sub> & PM<sub>2.5</sub> source apportionment study through receptor modelling using CMB8.2 model.
- 1.4. To conduct data collection surveys and calculate baseline emission loads of air pollutants including: PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>x</sub>, CO and NMVOCs originating from various sources for Bhubaneswar region for year 2022.
- 1.5. To project the baseline emission loads using growth rate method for future years (2027 and 2032) and plan control actions in consultation with stakeholders.
- 1.6. To generate the spatial distribution of PM<sub>10</sub> & PM<sub>2.5</sub> concentrations using AERMOD dispersion model.
- 1.7. To prepare a comprehensive action plan for reducing, control and abatement of PM<sub>10</sub> & PM<sub>2.5</sub>.
- 1.8. To prepare a rapid source apportionment study report, based on monitoring carried out in one season.
- 1.9. To provide adequate training to the OSPCB officials on source apportionment and emission inventory study

1.10. To submit the final detailed study report after carrying out monitoring for two seasons i.e. summer and winter, emission inventory, dispersion modelling, receptor modelling with complete data analysis and data validation

## 1.5. Integrated framework for source apportionment study

This section discusses the overall framework designed to carry out the present study. In general, two fundamental scientific approaches are used to identify and quantify the sources of particulate matter: (A) bottom-up or dispersion model-based approach (Fig. 4) and (B) top-down or receptor model-based approach (Fig. 5).



*Figure 4 Bottom-up approach for Particulate Matter Source Apportionment*

The bottom-up approach includes identification of air pollution sources and their emission strengths using activity data and available emission factors (Fig. 4). These emissions are then used as input to dispersion models such as AERMOD, WRF-Chem etc. along with meteorological parameters and land use characteristics to predict pollutant concentrations over space and time. The top-down approach on the other hand include sampling air at identified receptor locations and deducing the potential air pollution sources by correlating common physical and chemical characteristics between the sources and collected samples (Fig. 5). These two approaches and their inter-relations are described in a step-wise manner in the following sections.

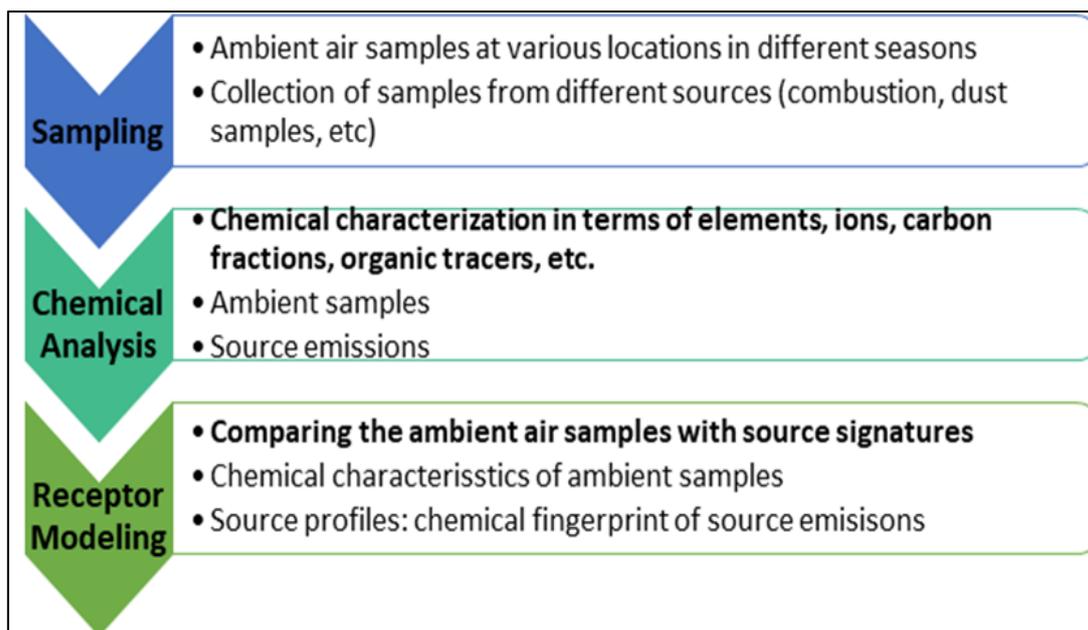


Figure 5 Top-down approach for Particulate Matter Source Apportionment

Fig. 6 illustrates the details of the integrated approach, combining the two approaches described above, adopted for Emission Inventory and Source Apportionment study of Bhubaneswar region in Odisha.

## 1.6. Organization of the Report

This report is organized into six chapters and a brief description of each chapter is given below:

**Chapter 1** presents the background of the study, brief description of the region, including geography, demography, weather and climate. The objectives, scope of the work and the integrated approach to this study are also briefly described in this chapter.

**Chapter 2** of this report presents the air quality status w.r.t. sampling and chemical characterization of particulate matter ( $PM_{10}$  and  $PM_{2.5}$ ) at five sampling sites for two critical seasons, i.e., winter and summer. This chapter also describes the details of site selection, PM sampling, instrumentation used in laboratory analysis, quality assurance and quality control (QA/QC) protocol, source apportionment using receptor model i.e. CMB. This chapter also discusses the site-wise, seasonal chemical composition of  $PM_{10}$  and  $PM_{2.5}$  and results of receptor modelling based source apportionment. The contribution of various sources at identified receptor sites and the region are also presented.

**Chapter 3** initially describes the sector-wise methodology adopted for developing an emission inventory of pollutants at the regional level, followed by results of emission inventory for various pollutants. This chapter also discusses the spatio-temporal variations in the emissions inventory.

**Chapter 4** presents the methodology adopted for dispersion modelling of air pollutants during the summer and winter seasons. This chapter further describes the analysis of dispersion modelling outputs in terms of model validation, seasonal changes and spatial distribution over the study domain.

**Chapter 5** describes the various emission control scenarios designed for Bhubaneswar region in future years i.e. 2027 and 2032 and analyses their impact in terms of emissions, air quality concentrations and AQI.

**Chapter 6** presents a comprehensive, sector-wise action plan for effective the prevention, control and abatement of air pollution based on the findings of this study.

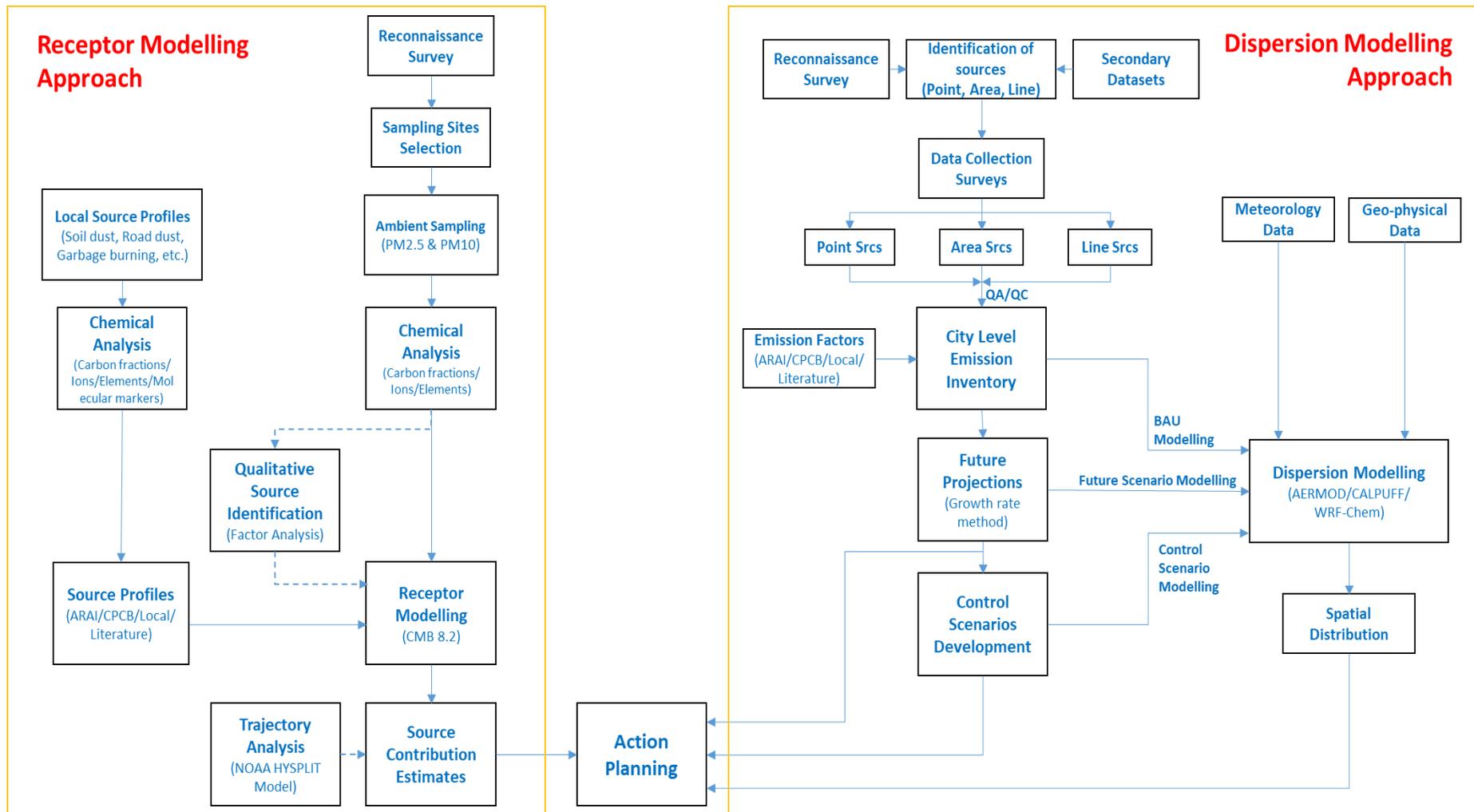


Figure 6 Framework for integrated emission inventory and source apportionment study of Bhubaneswar region in Odisha

## **Chapter 2: Air Quality Monitoring, Chemical Analysis & Receptor Modelling**

### **2.1. Introduction**

The main objective of ambient air quality monitoring was to generate the baseline data of ambient concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> and to identify the major sources contributing to it. Monitoring was conducted in two critical seasons i.e. winter and summer, to capture the seasonal variations. A comprehensive exercise to monitor air quality was carried out during winter season i.e. December 12 to 27, 2022 and summer season i.e. April 11 to 29, 2023 at 4 representative locations, having different land-use patterns and sources of activity.

### **2.2. Methodology**

#### **2.2.1. Sampling sites selection**

Based on the preliminary survey and inputs from State Pollution Control Board, Odisha (OSPCB) four sampling locations are identified for this study in Bhubaneswar region. Figure 7 and Table 1 respectively show the geographic distribution and details of the sampling sites, which include 1 background site, 1 residential site, 1 mixed land use site and 1 industrial site. These sites are located in different parts of study domain and can provide an integrated insight into the characteristic of PM<sub>2.5</sub> and PM<sub>10</sub> over Bhubaneswar region. For example, the residential sites, such as Office of Chief Instructress Home Economic Training Centre (S3), are surrounded by typical residential areas with middle-to-high income and low-income group households, respectively. The background site such as Gokhibaba Ashram (S1), is located in natural habitat, which are far away from anthropogenic emissions and are less influenced by human activities. The other two sites i.e. OSPCB Head Office (S2) and RO Office, SPCB (S4) typically represent mixed land use and industrial sites, respectively.

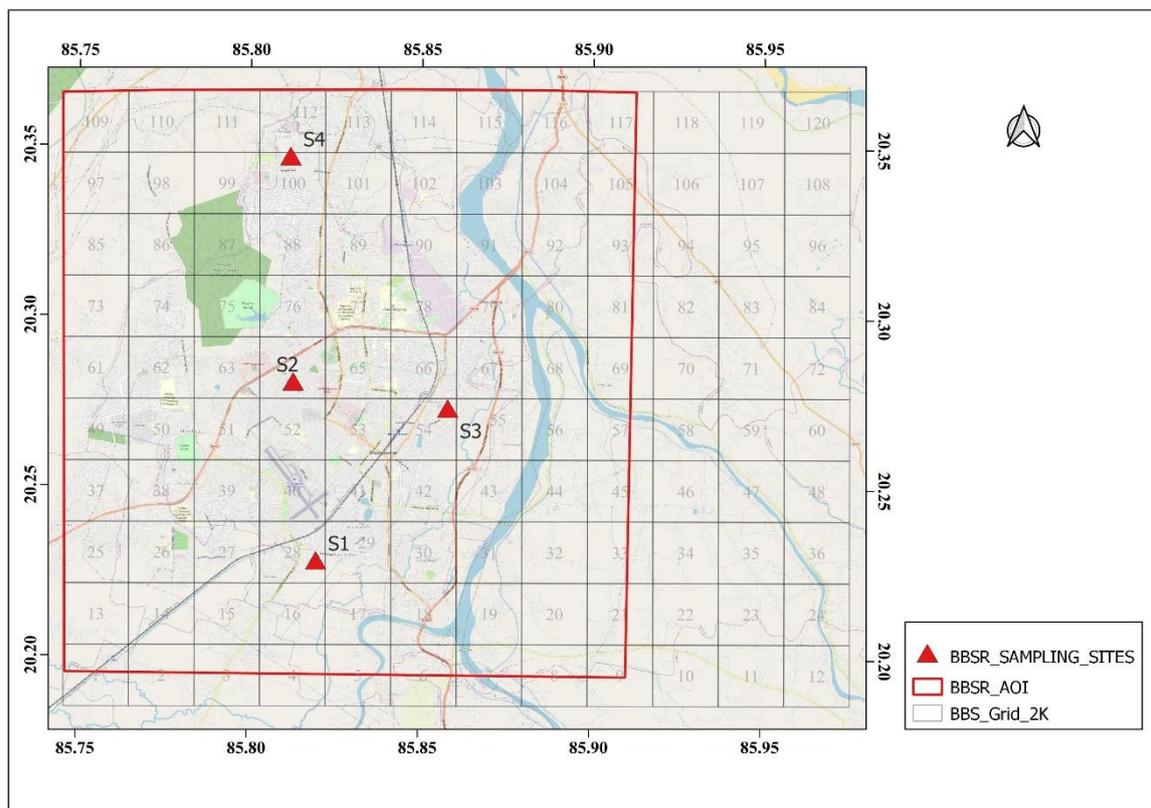


Figure 7 Bhubaneswar region map showing locations of four sampling sites (red triangles) selected for source apportionment study

Table 6 Geographic information of the selected sampling sites in Bhubaneswar region

Code	Location	Latitude	Longitude	Category
S1	Gokhibaba Ashram, Sundarpada	20° 13' 38.94" N	85° 49' 11.72" E	Background
S2	OSPCB Head Office, Nayapalli	20° 16' 48.01" N	85° 48' 46.47" E	Mixed
S3	Office of Chief Instructress Home Economic Training Centre, Jharpada	20° 16' 20.62" N	85° 51' 29.19" E	Residential (LIG and MIG)
S4	RO Office, SPCB, Patia	20° 20' 45.81" N	85° 48' 42.12" E	Industrial

### 2.2.2. Sampling schedule

The ambient PM<sub>2.5</sub> and PM<sub>10</sub> samples were collected in the study area, during two critical seasons i.e. winter and summer. As shown in Fig. 8, the winter season sampling was conducted at identified locations from December 12 to 22, 2022 while summer season sampling was conducted from April 11 to 29, 2023.

W I N T E R	SITE	Dec-22																		
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	GOKHIBABA ASHRAM																			
	OSPCB HEAD OFFICE																			
	OFFICE OF CHIEF INSTRUCTRESS HOME ECONOMIC TRAINING CENTRE																			
	RO OFFICE SPCB																			

S U M M E R	SITE	Apr-23																		
		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	GOKHIBABA ASHRAM																			
	OSPCB HEAD OFFICE																			
	OFFICE OF CHIEF INSTRUCTRESS HOME ECONOMIC TRAINING CENTRE																			
	RO OFFICE SPCB																			

*Figure 8 The sampling schedule for collection of PM samples during winter and summer seasons in Bhubaneswar region*

### 2.2.3. Sampling and gravimetric analysis

PM<sub>2.5</sub> and PM<sub>10</sub> samples were collected using multi-channel speciation samplers for 24 hours at a flow rate of 16.7 LPM during both the winter and summer seasons. Samples were simultaneously collected on 47 mm diameter polytetrafluoroethylene (PTFE) membrane filters (Whatman make; GE Healthcare Life Sciences, India) and quartz fiber filters (Tissuequartz™ 2500QAT-UP; Pall Corporation, USA) for both PM<sub>2.5</sub> and PM<sub>10</sub>. Teflon filters were used for measurement of gravimetric mass, elemental concentrations, and water-soluble ions while the quartz-fiber filters were analyzed for carbonaceous materials. Each filter paper was visually inspected for damage, if any, before and after sampling. The filter papers were conditioned before and after sampling in desiccators to attain equilibration under the controlled temperature (20 – 30 °C) and relative humidity (20 – 35%) for 24 hours. Additionally, the quartz-fiber filter papers were pre-baked at 900 °C for 3 hours in an oven to remove any deposited organic compounds. The conditioned filters were transferred to individual cassettes to avoid the contamination of filters on the way and cassettes were then stored at ~4 °C to minimize the evaporation of volatile compounds. Filters were handled only using tweezers coated with

Teflon tape to reduce the possibility of contamination. As discussed earlier, Teflon filter papers were weighed before and after sampling for the determination of collected particulate mass using a Mettler Toledo electronic microbalance (Model: XP2U).

#### **2.2.4. Chemical analysis of PM**

The chemical speciation analysis of PM samples collected on filter papers can be divided into the three most common categories i.e. elements, ions (sulphates, nitrates, ammonium, and others), and carbon fractions for identifying the sources of pollutants in Bhubaneswar region. The details of the instrumental techniques utilized for analysing PM are given below.

##### **2.2.4.1. Elemental/Organic Carbon**

Two classes of carbon are commonly measured in aerosol samples collected on quartz fibre filters: 1) organic, volatilized, or non-light absorbing carbon and 2) elemental or light-absorbing carbon.

‘Organic carbon’ and ‘elemental carbon’ generally refer to particles that appear black and are also called ‘soot’, ‘graphitic carbon’, or ‘black carbon’. Various methods include thermal/optical reflectance (TOR), thermal/optical transmission (TOT), and thermal manganese oxidation (TMO) methods for organic and elemental carbon. TOR method of analysis was used for carbon fractions. DRI Model 2015 (Series 2) Multi-Wavelength Thermal/Optical Carbon Analyzer was used for the carbon-measurement study. Pre-baked filters were used for carrying out blank analysis.

##### **2.2.4.2. Elements**

The energy dispersive X-ray fluorescence (ED-XRF) technique was used for the quantification of elements present in PM<sub>2.5</sub> and PM<sub>10</sub> collected on Teflon paper. It is a non-destructive technique of inorganic speciation analysis; XRF does not require sample preparation or long operator time after it is loaded into the analyzer. Filters remain intact after analysis and were used for analysis of ions.

##### **2.2.4.3. Ions**

Ionic species are those that are soluble in water. Anions and cations were analyzed using an ion chromatograph with conductivity detector. In PM<sub>2.5</sub> and PM<sub>10</sub> samples, ions that are

analysed on an ion chromatograph are grouped under anions such as fluoride, chloride, bromide, nitrite, nitrate, sulphate and under cations such as sodium, ammonium, potassium, calcium, and magnesium. Sample preparation was done by using the ultrasonication method. Milli-Q grade water, freshly produced from the Gradient A10 Millipore system and having resistivity of 18 M-Ohm, was used for sample preparation and analysis. Laboratory blank, field blank, and samples were always filtered through 0.2-micron nylon membrane filters to avoid background matrix interference.

#### **2.2.4.4. Molecular Markers**

After the carbon analysis, remaining PM samples on quartz filters were used for molecular marker analysis. For analysis of molecular markers, the daily PM samples were extracted together, to form composite samples and have sufficient mass to represent the whole monitoring period. Prior to analysis, composite samples were extracted by Soxhlet extraction with 1:1 dichloromethane: acetone solvent mixture for a period of 16 hrs. The extracts were evaporated to 4 ml by using a Kuderna-Danish apparatus. Gas chromatography – mass spectrometry (GC-MS) system (GC-MS Make; Thermofisher Scientific) with TB5 column was used for quantitative determination of 53 molecular marker species listed in Table 2. A five-point calibration curve in SIM mode was obtained for determining concentrations of the molecular markers in the particulate samples. All the molecular markers are identified by comparing retention times and mass spectra with the calibration standards and National Institute of Standards and Technology (NIST) spectral reference library. The molecular markers were first identified by comparing the retention time with standards within a window of  $\pm 0.1$  min, secondly the quantification ions, and finally the particular ratios of several relatively abundant ions.

*Table 2 List of molecular markers species analysed in PM<sub>2.5</sub> and PM<sub>10</sub> fractions*

Sr. No.	Class	Species
1.	<b>Alkanes</b>	n-Heptane, n-Octane, n-Nonane, n-Decane, n-Undecane, n-Dodecane, n-Tridecane, n-Tetradecane, n-Hexadecane, n-Pentadecane, n-Heptadecane, n-Octadecane, n-Nonadecane, n-Eicosane, n-Heneicosane, n-Docasane, n-Tricosane, n-Tetracosane, n-Pentacosane, n-Hexacosane, n-Heptacosane, n-Octacosane, Nonacosane, n-Tricontane, n-Hentriacontane, n-Dotriacontane, n-Tritriacontane, n-Tetracontane, n-Pentatriacontane, n-Hexatriacontane, Heptatriacontane, Octatriacontane, Nonatriacontane, n-Tetracontane
2.	<b>Polycyclic Aromatic Hydrocarbons (PAHs)</b>	Naphthalene, Acenaphthalene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo(e)pyrene, Benzo[a]pyrene Perylene, Indeno[1,2,3,-cd]pyrene, Dibenz[a,h]anthracene, Benzo[g,h,i]perylene
3.	<b>Alkanoic acids</b>	Hexadecanamide, Octadecanamide
4.	<b>Others</b>	Levoglucosan, Stigmasterol

### **2.2.5. Gases and Volatile Organic Compounds (VOCs)**

As described in the Scope of Work section, in addition to particulate matter the present study also analysed the levels of gaseous pollutants such as SO<sub>2</sub> and NO<sub>2</sub> and Volatile Organic Compounds (VOCs) such as Benzene, Toluene, Ethyl Benzene and Xylene, during winter season only. This section explains the details of sampling and chemical analysis methodology followed.

The gaseous samples for ambient SO<sub>2</sub> and NO<sub>2</sub> determination, were collected at four sampling sites, on daily basis during the winter season sampling period i.e. December 12 to 22, 2022. The samples were collected by sampling for 24-hours, at a flowrate of 0.2 LPM, in two separate impingers containing appropriate absorbing solutions for SO<sub>2</sub> and NO<sub>2</sub>. The ambient SO<sub>2</sub> and NO<sub>2</sub> concentrations were determined in the laboratory following the procedure prescribed in Indian standard IS:5182, 2001, RA 2017, part 2 and 6, respectively.

For determination of Volatile Organic Compounds (VOCs) in the ambient air, the grab samples were collected, at four sampling sites, in Tenax sorbent tubes (Make; Markes International) for 15 minutes at a flow rate of 3 LPM. Before sampling, these sorbent tubes were pre-conditioned at 320°C and screened for contamination. To prevent contamination during shipping, the conditioned tubes are sealed with brass storage caps. The quantitative analysis of benzene, toluene, ethylbenzene and xylene (BTEX), collected using Tenax sorbent tubes, was carried out by Gas chromatography – mass spectrometry method (GC-MS, Make; Thermofisher Scientific, TD make; Markes International). A three-point calibration curve was obtained for determining concentrations of BTEX in full scan mode. BTEX compounds were identified by comparing retention time with standards and National Institute of Standards and Technology (NIST) spectral reference library.

## **2.3. Quality Assurance/Quality Control**

Quality assurance (QA)/quality control (QC) is an essential part of any monitoring system. It is a programme of activities that ensures that the measurements meet the defined and appropriate standards of quality, with a stated level of confidence. Each sample to be sent to the field for monitoring was prepared carefully by following the QA/QC system. A unique sample ID was given to each sample collected for future reference and database generation.

The Instrumex make dual channel speciation samplers were used for particulate sampling during both the seasons. The field staff, handling the sample kit, were trained for specific tasks like the handling of filters and cartridges. Proper training was provided to the field staff and supervisors for conducting intermediate performance checks. The details of QA/QC audits performed are presented in Annexure-F.

## 2.4. Chemical Mass Reconstruction

The chemical mass reconstruction is carried out following the methodology adopted by Bawase et al., 2021 and Chow et al., 2015. The PM chemical components were grouped into six categories i.e. organic matter (OM), elemental carbon (EC), sulphate, nitrate and ammonium ions (together referred to as SNA), seas salts (SS), crustal materials (CM) and other trace elements (TE) and reconstructed PM mass is calculated as follows (Eq. 1):

$$PM_{Chem} = OM + EC + SNA + SS + CM + TE \dots \dots \dots Eq. (1)$$

Organic Mass (OM) was obtained by multiplying the measured concentration of organic carbon (OC) by a factor of  $1.6 \pm 0.2$ , to account for the ageing effect of urban aerosols (Turpin and Lim, 2001). It is to be noted, that this approach may introduce some uncertainties in the overall estimations of OM to the total mass.

In this study, secondary ions are expressed as sums of sulphate, nitrate and ammonium ions while the sea salts are expressed as sum of sodium and chloride ions.

The crustal mass was obtained using IMPROVE formula (Malm et al. 1994, Eq. 2). This formula estimates crustal mass on the basis of elemental oxides such as  $Al_2O_3$ ,  $SiO_2$ ,  $CaO$ ,  $TiO_2$ , and  $Fe_2O_3$ .

$$CM = 2.2 * Al + 2.49 * Si + 1.63 * Ca + 1.94 * Ti + 2.42 * Fe \dots \dots \dots Eq. (2)$$

The trace element mass is the sum of 14 different elemental species and is expressed as (Eq. 3):

$$\begin{aligned} \text{TE} = & \text{K} + \text{V} + \text{Cr} + \text{Mn} + \text{Co} + \text{Ni} + \text{Cu} + \text{Zn} + \text{As} + \text{Se} + \text{Rb} + \text{Sr} + \text{Mo} + \text{Pd} \\ & + \text{Cd} + \text{Sn} + \text{Te} + \text{Cs} + \text{Ba} + \text{La} \\ & + \text{Pb} \dots \dots \dots \text{Eq. (3)} \end{aligned}$$

The chemical reconstruction method explained above was applied to all 4 sites over Bhubaneswar city and reconstructed PM mass (PM<sub>Chem</sub>) was compared against the corresponding observed gravimetric mass (PM<sub>Grav</sub>).

## 2.5. Receptor Modelling: Chemical Mass Balance (CMB) Model

In the present study, the US EPA-Chemical Mass Balance Model (CMB V8.2; Coulter 2004) is used to apportion the sources of PM<sub>2.5</sub> and PM<sub>10</sub> particles in Bhubaneswar region. This model uses an effective variance least-squares algorithm to apportion the ambient data to selected source profiles (Gordon 1980; Hidy and Venkataraman 1996; Watson 1984; Watson, et al. 1984). The basic principle of the CMB model could be expressed by Equation (4), which represents the relationship between the ambient concentrations of the chemical species at a receptor site and those emitted from the source.

$$C_i = \sum_{j=1}^P F_{ij} \times S_j \dots \dots \dots \text{Eq (4)}$$

In this equation, C<sub>i</sub> is the ambient concentrations of the species i measured at the receptor site, P is the number of contributing sources, F<sub>ij</sub> is the fraction of the emissions of the species i starting from the source j, and S<sub>j</sub> indicates the ambient contribution of the source j (Srivastava and Jain, 2007).

The CMB model uses ambient pollutant concentrations, their chemical composition, and the chemical composition of sources i.e. source profiles, to estimate the relative contribution of each source to ambient concentrations at a given location. The CMB model also considers the known uncertainties in the ambient measurements and the source profiles.

As discussed above, source profiles are one of the essential requirements of receptor modelling using CMB. The source profiles in a given region depends upon sources, process operating conditions, geology, and geographic seasonality (Patil et al., 2013) and hence the choice of appropriate source profiles is very crucial in source identification and apportionment. India specific source profiles for a number of vehicular and non-vehicular sources were

generated by CPCB source apportionment study (CPCB, 2010) and the same have been used in this study. A detailed description of the source profiles can be found in references CPCB (2010) and Patil et al. (2013).

The CMB model was run for each site for each day of sampling. The performance of the CMB model was examined using parameters such as squared correlation coefficient ( $R^2$ ), measured fitting species concentration ( $\chi^2$ ), model computed per cent mass, and ratio of residual to uncertainty (R/U ratio). The daily source contributions obtained from the CMB model are averaged over the sampling period in each season to get the seasonal source contributions for each site.

## **2.6. Results and discussions**

### **2.6.1. Winter season**

#### **2.6.1.1. PM mass concentrations**

Fig. 9, presents the distribution of daily PM<sub>2.5</sub> and PM<sub>10</sub> concentrations observed at four sampling locations in Bhubaneswar region during the winter season i.e. Dec 12 – 27, 2022. The mean PM<sub>2.5</sub> and PM<sub>10</sub> mass concentrations during the entire sampling period over all sites were 81.9 and 183.1  $\mu\text{g}/\text{m}^3$ , respectively. The mean PM<sub>2.5</sub> concentrations exhibited a 3-fold range and ranged from a minimum of 39.9  $\mu\text{g}/\text{m}^3$  (at Gokhibaba Ashram i.e. S1) to a maximum of 135.4  $\mu\text{g}/\text{m}^3$  (at Gokhibaba Ashram i.e. S1). Similarly, the mean PM<sub>10</sub> concentrations exhibited a 4-fold range and ranged from 87.4  $\mu\text{g}/\text{m}^3$  (at Office of Chief Instructress Home Economic Training Centre i.e. S3) to 331.6  $\mu\text{g}/\text{m}^3$  (at OSPCB Head Office i.e. S2). The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100  $\mu\text{g}/\text{m}^3$  for PM<sub>2.5</sub> and PM<sub>10</sub>, respectively. The winter-time PM<sub>2.5</sub> concentrations were observed to exceed the daily NAAQS limit at all sites (73.3 to 86.7%) with minimum exceedance at S3, i.e. Office of Chief Instructress Home Economic Training Centre (73.3%). The daily averaged PM<sub>10</sub> concentrations exceeded the NAAQS limit at all sites (86.7-100%) with minimum exceedance at S3, i.e. Office of Chief Instructress Home Economic Training Centre (86.7%) whereas maximum PM<sub>10</sub> exceedance was observed at S2 i.e. OSPCB Head Office and S4 i.e. RO Office, SPCB (100%) respectively.

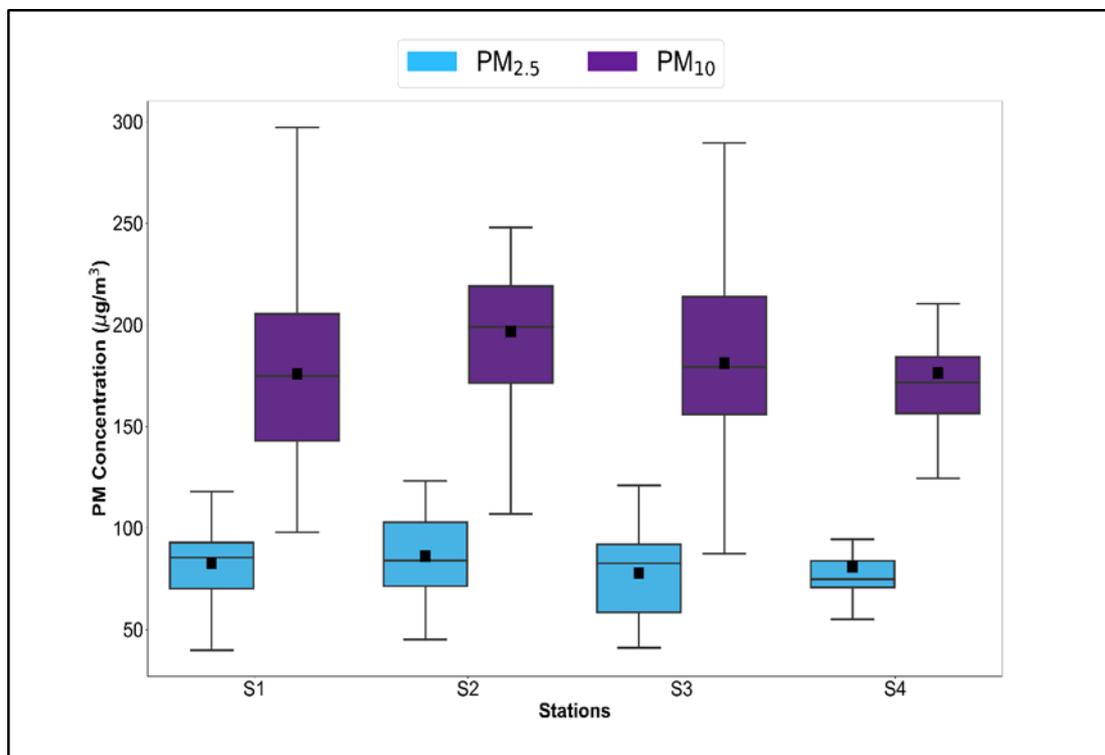
#### **2.6.1.2. Spatial variability**

The highest seasonal mean PM<sub>2.5</sub> concentrations were observed at S2 i.e. OSPCB Head Office (86.6  $\mu\text{g}/\text{m}^3$ ) while the lowest were recorded at S3, i.e. Office of Chief Instructress Home Economic Training Centre (77.7  $\mu\text{g}/\text{m}^3$ ). The PM<sub>2.5</sub> concentration showed highest variability at S1 i.e. Gokhibaba Ashram and S3 i.e. Office of Chief Instructress Home Economic Training Centre locations reported the highest and lowest variability in PM<sub>2.5</sub> concentrations, respectively. For example, PM<sub>2.5</sub> concentrations ranged from 39.9 to 135.4 at S1 i.e. Gokhibaba Ashram while it ranged from 41.1 to 121.0 at S3, i.e. Office of Chief Instructress Home Economic Training Centre.

The highest seasonal mean PM<sub>10</sub> concentrations were observed at S2 i.e. OSPCB Head Office (198.0  $\mu\text{g}/\text{m}^3$ ) while the lowest were recorded at S1 i.e. Gokhibaba Ashram (175.9  $\mu\text{g}/\text{m}^3$ ). The PM<sub>10</sub> concentrations showed highest variability at S2 i.e. OSPCB Head Office

ranging from a minimum of 106.9 to a maximum of 331.6  $\mu\text{g}/\text{m}^3$  while it ranged between 87.4 and 289.6  $\mu\text{g}/\text{m}^3$  at S3 i.e. Office of Chief Instructress Home Economic Training Centre.

These concentration levels can be attributed to air polluting activities around each site. For example, S2 i.e. OSPC Head Office Site is located in the heart of the Bhubaneswar city and surrounded by dense road network and population and will be mainly impacted by traffic related PM. In addition to traffic emissions, road dust re-suspension due to movement of vehicles in the region can be one of the major reasons for highest particulate levels.



*Figure 9 Boxplot showing distribution of daily  $\text{PM}_{2.5}$  (blue colored boxes) and  $\text{PM}_{10}$  (violet colored boxes) concentrations observed at five sampling sites in Bhubaneswar region during the winter season sampling period (Dec 12 – 27, 2022).*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

### 2.6.1.3. Temporal variability

Fig. 10 shows daily time-series of PM<sub>2.5</sub> and PM<sub>10</sub> observed at four selected sampling locations in Bhubaneswar region during the winter season sampling period. Only valid samples between Dec 12 - 27, 2022 are considered for this analysis. Overall, the PM concentrations showed an increasing trend from December 12 to 23 at all sites, followed by a sharp decline towards end of winter season sampling period. This could be attributed to the meteorological phenomena over Bhubaneswar region during the winter season.

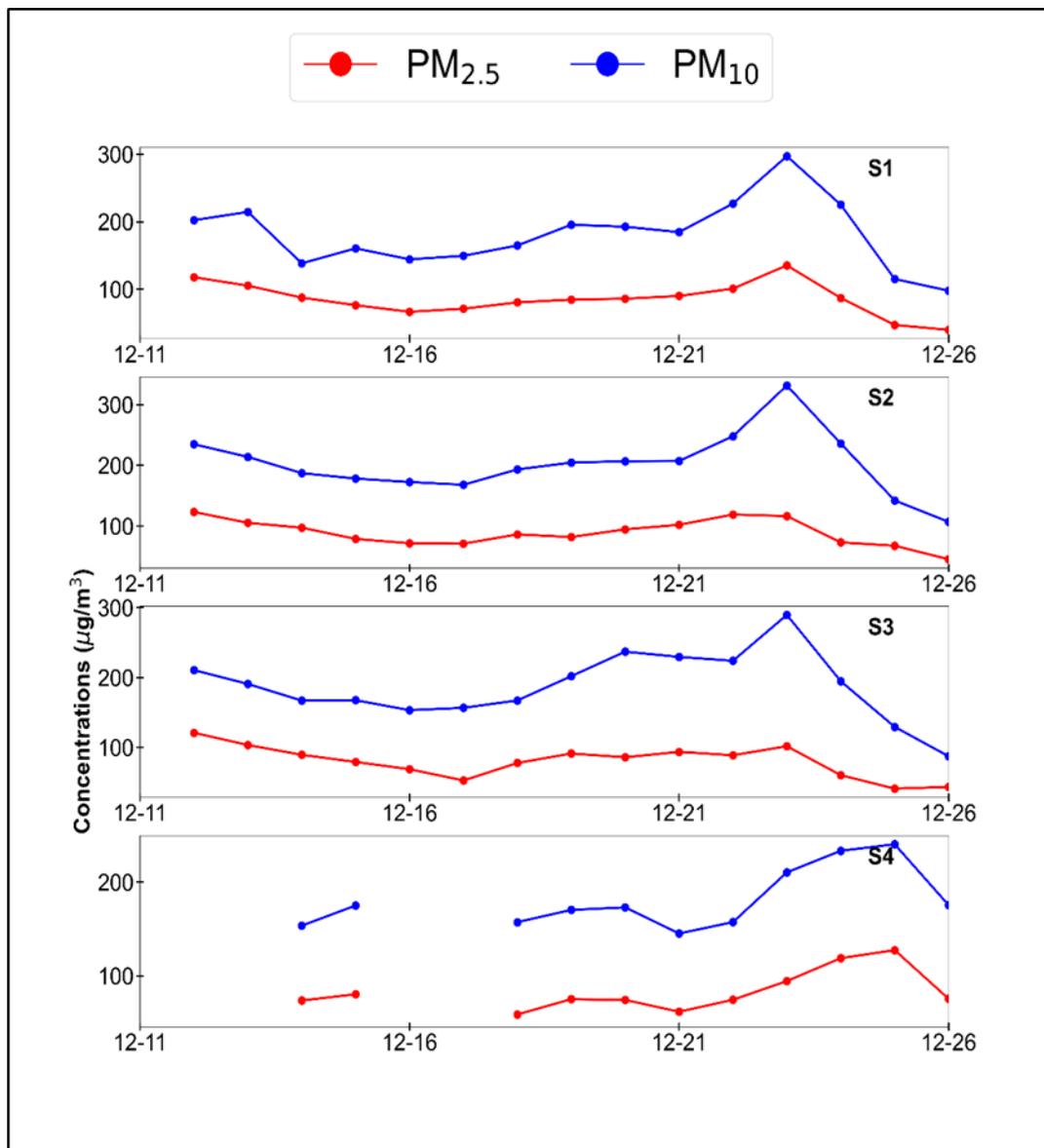


Figure 10 Daily time-series of PM<sub>2.5</sub> (red) and PM<sub>10</sub> (blue) concentrations observed at four sites in Bhubaneswar region during the winter season sampling (Dec 12-27, 2022)

#### 2.6.1.4. PM<sub>2.5</sub> to PM<sub>10</sub> ratios

Fig.11 shows distribution of daily PM<sub>2.5</sub> to PM<sub>10</sub> ratios observed at four selected sites during the winter season sampling. The average value of PM<sub>2.5</sub> to PM<sub>10</sub> ratios during the study period over all sites was found to be 0.45, varying from 0.31 to 0.63. The highest winter season mean PM<sub>2.5</sub> to PM<sub>10</sub> ratio was observed at S1 i.e. Gokhibaba Ashram (0.63) while the lowest was observed at S2 i.e. OSPCB Head Office (0.31). This variability in fine and coarse mode particles may be attributed to variability in PM chemical composition, which is in turn affected by various sources and meteorological conditions.

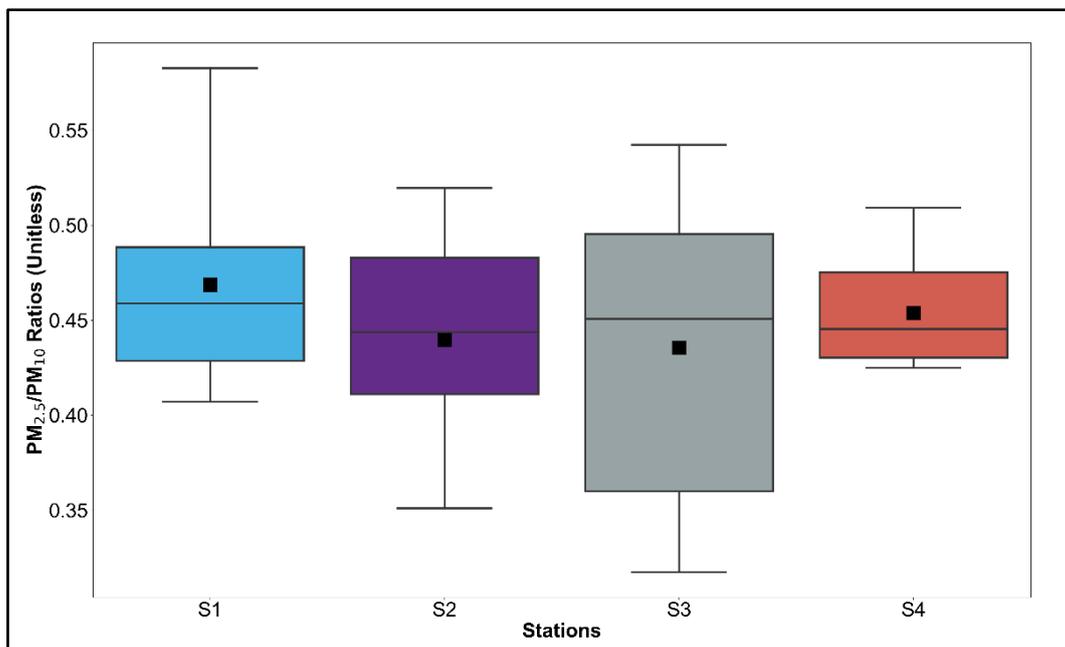


Figure 11 Boxplot showing distribution of PM<sub>2.5</sub> to PM<sub>10</sub> ratios at four selected sites in Bhubaneswar region during the winter season (Dec 12-27, 2022)

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

### 2.6.1.5. Chemical composition of PM<sub>2.5</sub> and PM<sub>10</sub>

#### 2.6.1.5.1. Site 1: Gokhibaba Ashram, Sundarpada

Fig. 12 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions (Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, and SO<sub>4</sub><sup>2-</sup>) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in PM<sub>2.5</sub> and PM<sub>10</sub> observed at Gokhibaba Ashram site (S1) in Bhubaneswar region during the winter season. OC, EC, SO<sub>4</sub><sup>2-</sup> and SNA in PM<sub>2.5</sub> and OC, EC, SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup> in PM<sub>10</sub> are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m<sup>3</sup>. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

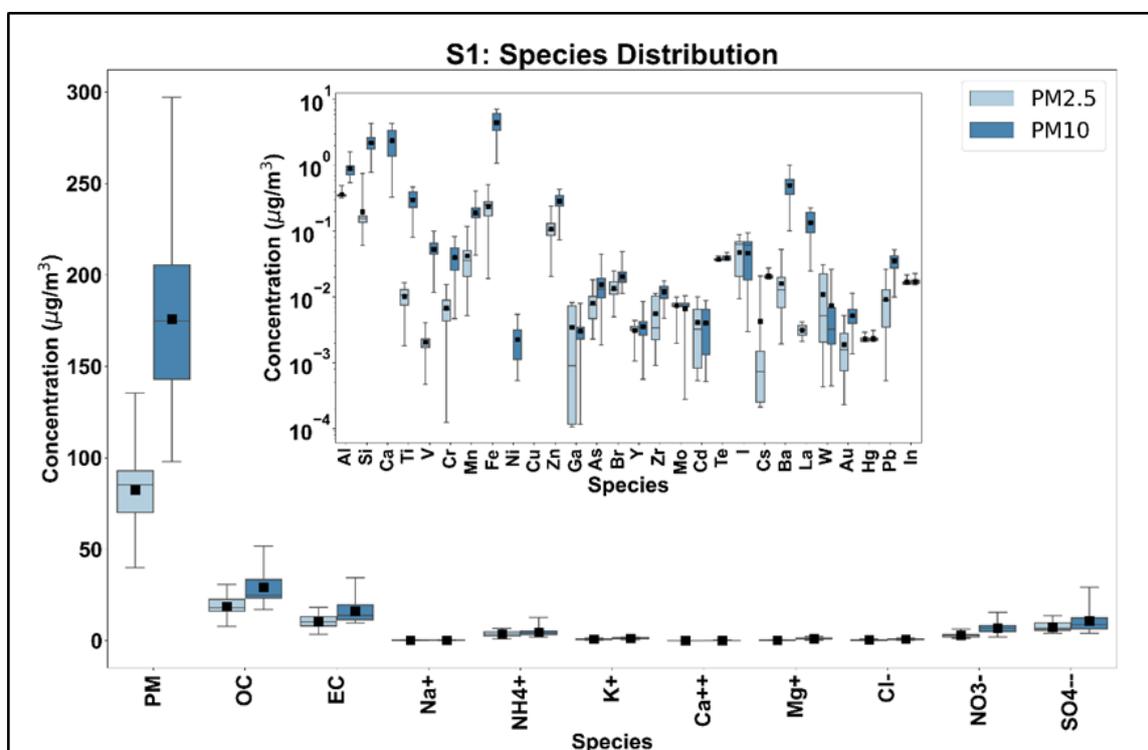


Figure 12 Box plots showing distribution of different species observed in PM<sub>2.5</sub> and PM<sub>10</sub> at Gokhibaba Ashram site (S1) in Bhubaneswar region during the winter season

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5.2. Site 2: OSPCB Head Office (S2)

Fig. 13 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions ( $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{2-}$ ) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Y, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  observed at OSPCB Head Office, Nayapalli (S2) during winter season (December 12-27, 2022). OC, EC,  $\text{SO}_4^{2-}$ , and SNA in  $\text{PM}_{2.5}$  and OC, EC,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  in  $\text{PM}_{10}$  are the most abundant species having seasonal mean concentrations greater than  $5.0 \mu\text{g}/\text{m}^3$ . Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

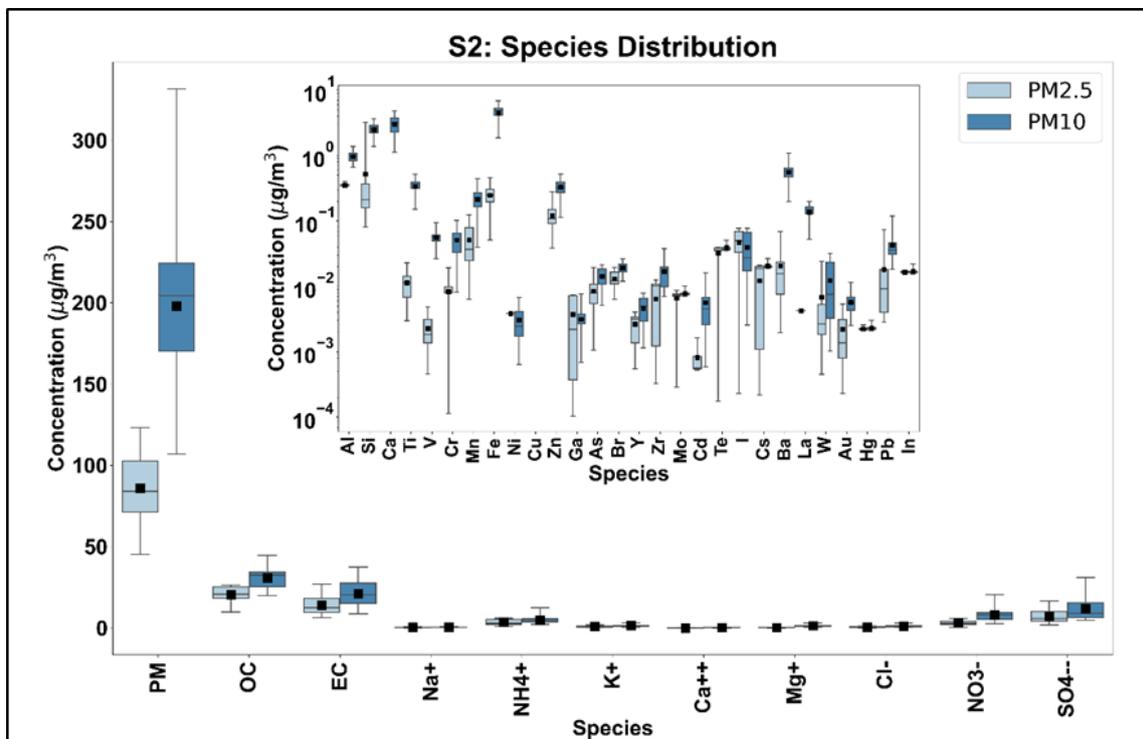


Figure 13 Box plots showing distribution of different species observed in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  at OSPCB Head Office (S2) in Bhubaneswar region during the winter season

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5.3. Site 3: Office of Chief Instructress Home Economic Training Centre -  
CIHETC (S3)

Fig. 14 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions ( $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{--}$ ) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  observed at Office of Chief Instructress Home Economic Training Centre – CIHETC, Jharpada (S3) in Bhubaneswar region during the winter season. OC, EC and  $\text{SO}_4^{--}$  in  $\text{PM}_{2.5}$  and OC, EC,  $\text{SO}_4^{--}$  and  $\text{NO}_3^-$  in  $\text{PM}_{10}$  are the most abundant species having seasonal mean concentrations greater than  $5.0 \mu\text{g}/\text{m}^3$ . Trace elements concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

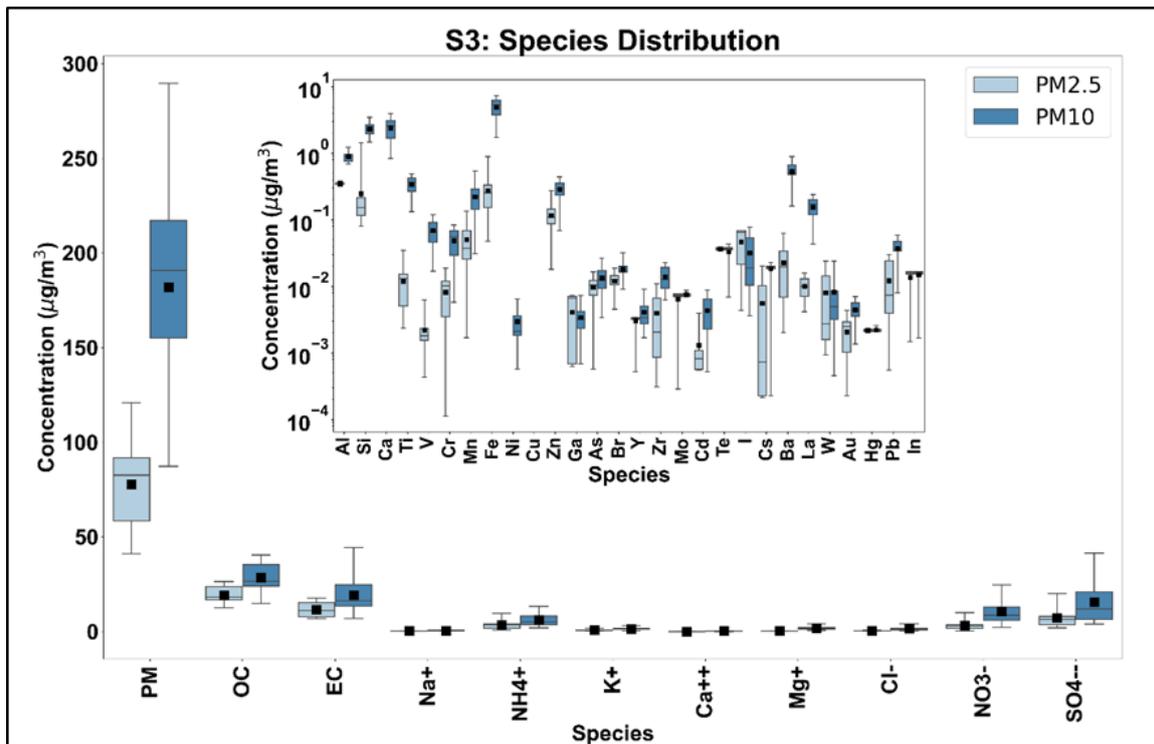


Figure 14 Box plots showing distribution of different species observed in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  at Office of Chief Instructress Home Economic Training Centre – CIHETC site (S3) in Bhubaneswar region during the winter season

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5.4. Site 4: RO Office, SPCB (S4)

Fig. 15 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions ( $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{--}$ ) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  observed at RO Office, SPCB, Patia (S4) in Bhubaneswar region during the winter season. OC, EC, and  $\text{SO}_4^{--}$  in  $\text{PM}_{2.5}$  and OC, EC,  $\text{SO}_4^{--}$  and  $\text{NO}_3^-$  in  $\text{PM}_{10}$  are the most abundant species having seasonal mean concentrations greater than  $5.0 \mu\text{g}/\text{m}^3$ . Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

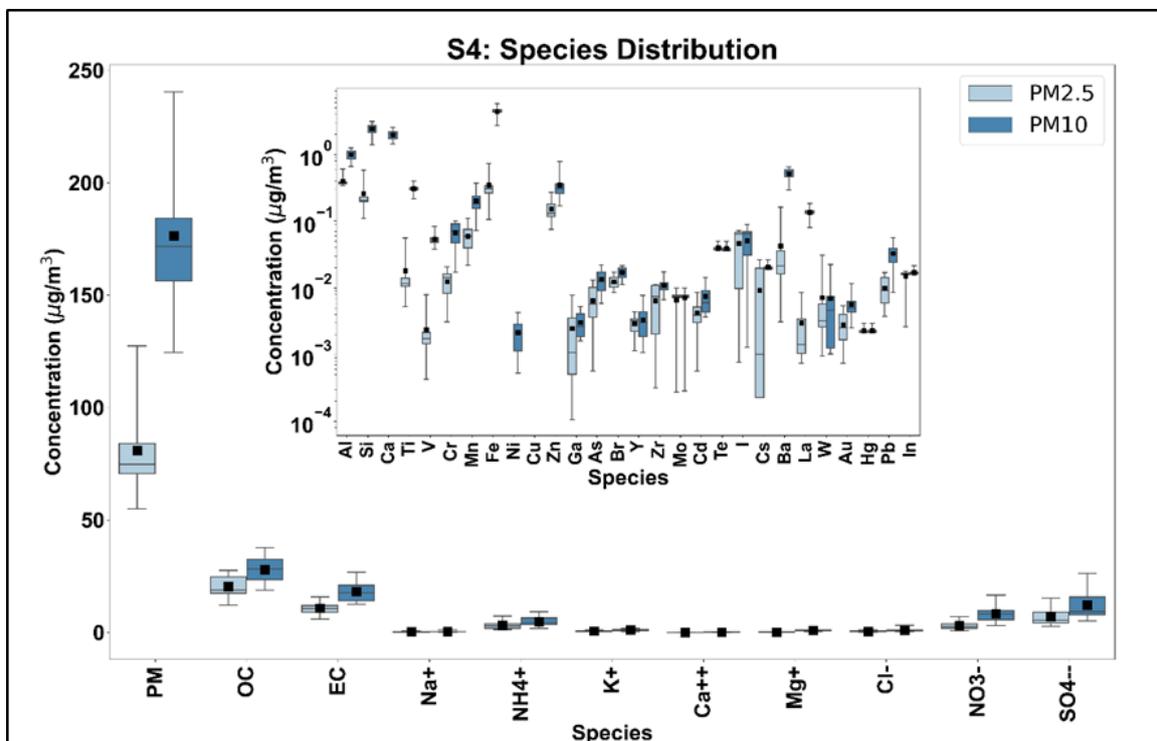
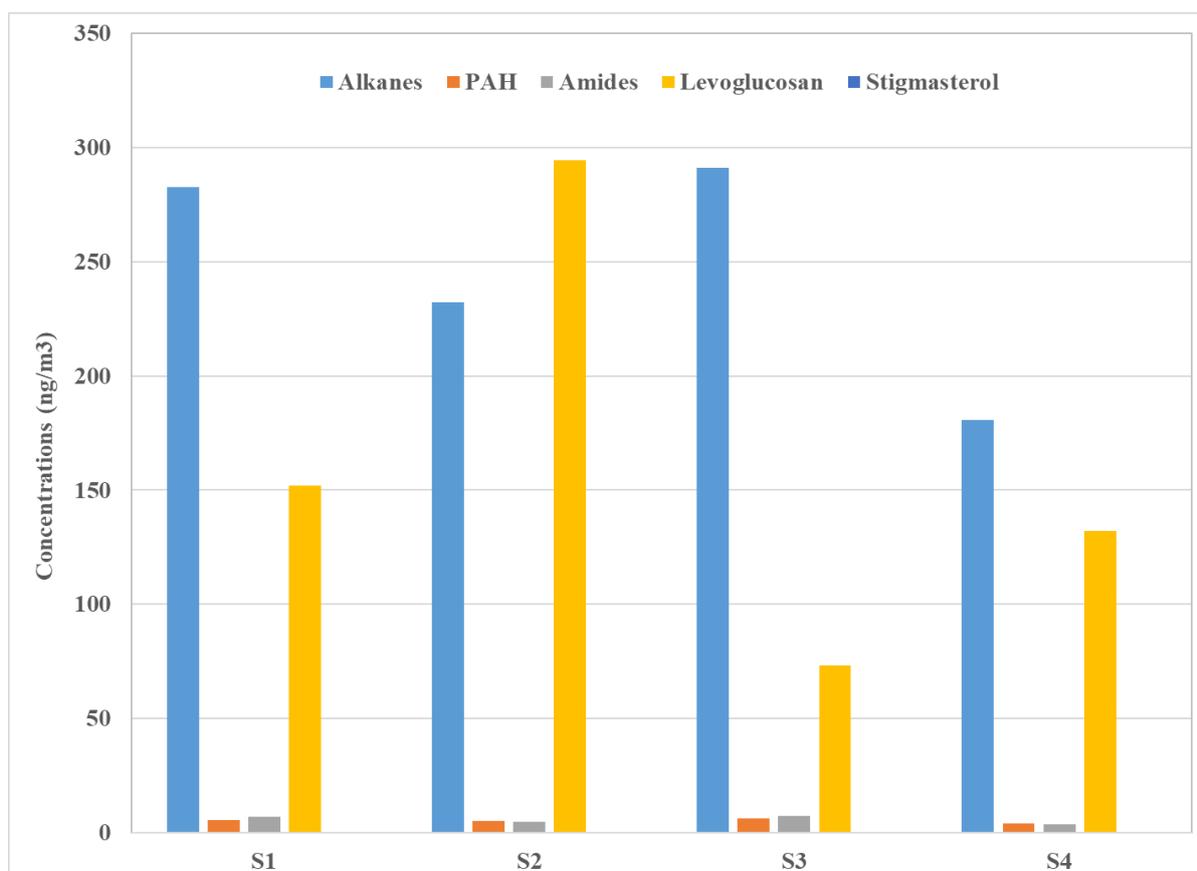


Figure 15 Box plots showing distribution of different species observed in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  at RO Office, SPCB, Patia (S4) in Bhubaneswar region during the winter season

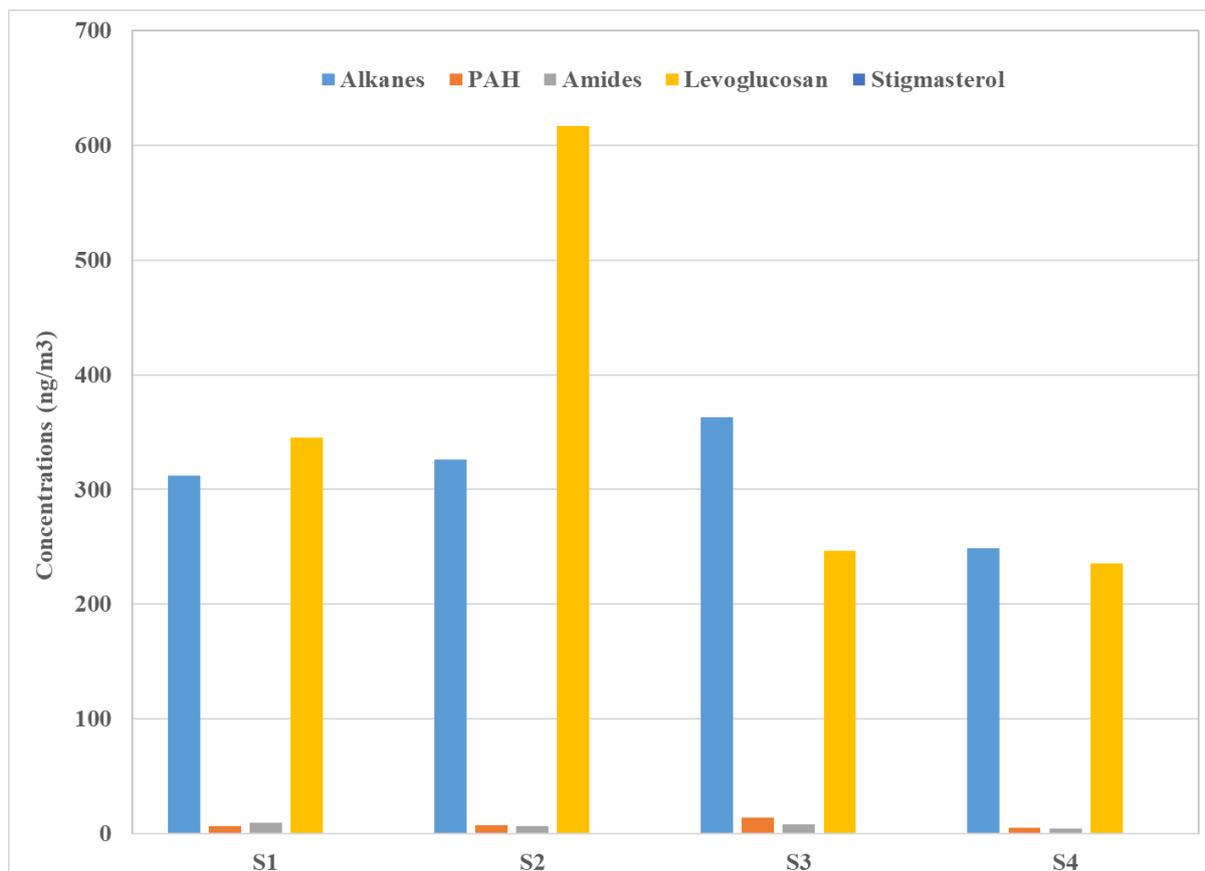
Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

### 2.6.1.6. Molecular Markers in PM<sub>2.5</sub> and PM<sub>10</sub>

Fig. 16, represents the seasonal mean concentrations of molecular markers observed at four sampling locations in Bhubaneswar region, during the winter season sampling period i.e. December 12 to 27, 2022. Alkane group is found to dominate the molecular markers mass, during the winter season over Bhubaneswar region. Besides Alkanes, Levoglucosan, which is considered as tracer for biomass burning emissions (CPCB, 2010), is also detected in significant amounts, in PM samples collected over Bhubaneswar region during winter season.



*Figure 16: The seasonal mean concentrations of molecular marker species in PM<sub>2.5</sub> (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Bhubaneswar region during the winter season sampling period (December 12-27, 2022).*



*Figure 17: The seasonal mean concentrations of molecular marker species in PM<sub>10</sub> (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Bhubaneswar region during the winter season sampling period (December 12-27, 2022).*

#### 2.6.1.7. Gaseous pollutants and VOCs

Fig. 18, represents the seasonal mean concentrations of gaseous pollutants i.e. SO<sub>2</sub> and NO<sub>2</sub> observed at four sampling locations in Bhubaneswar region, during the winter season sampling period i.e. December 12 to 27, 2022.

The winter season SO<sub>2</sub> concentrations were less than 5 µg/m<sup>3</sup> at all sites and hence are reported as Below Detection Limit (BDL). The winter season mean concentrations of NO<sub>2</sub> are observed to be 22.4 µg/m<sup>3</sup> at Gokhibaba Ashram, Sundarpada (S1), 37.4 µg/m<sup>3</sup> at OSPCB Head Office, Nayapalli (S2), 18.9 µg/m<sup>3</sup> at CIHETC, Jharpada (S3) and 29.9 µg/m<sup>3</sup> at RO Office, SPCB, Patia (S4).

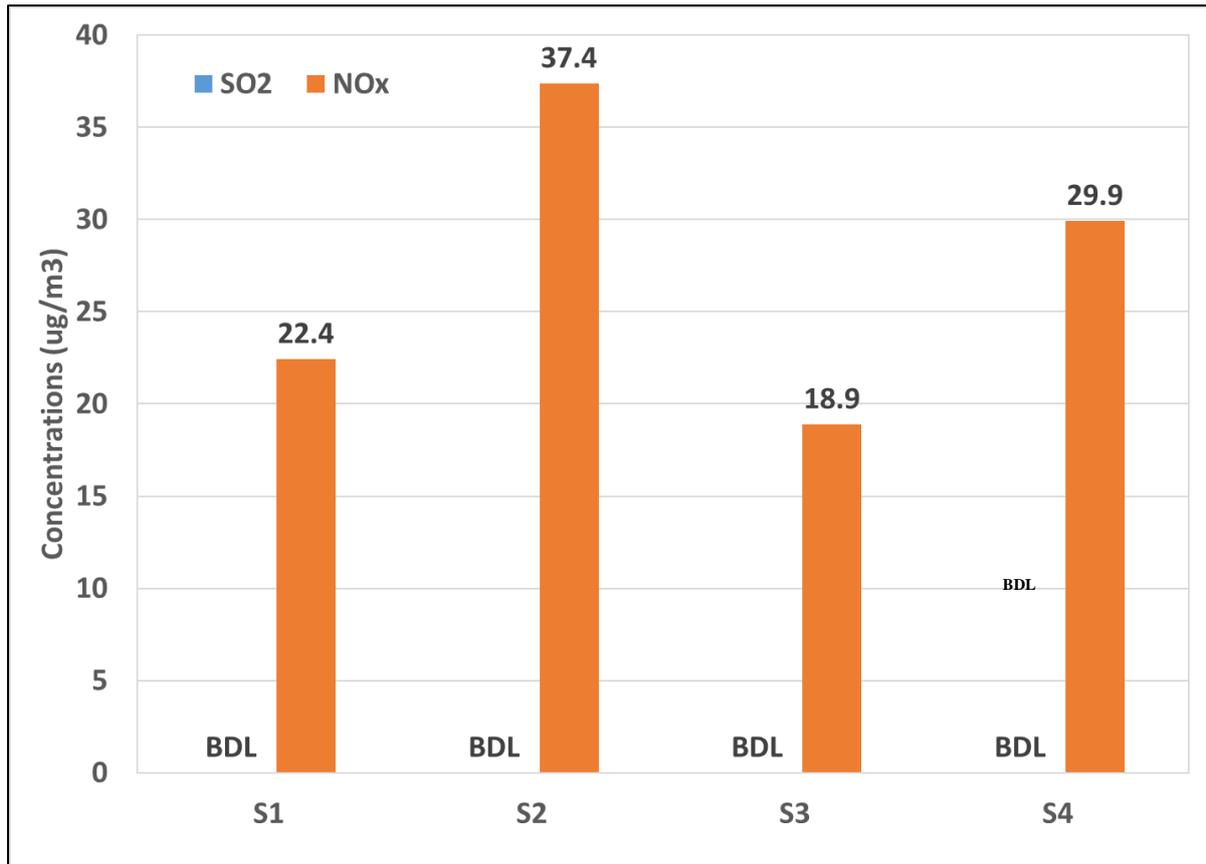
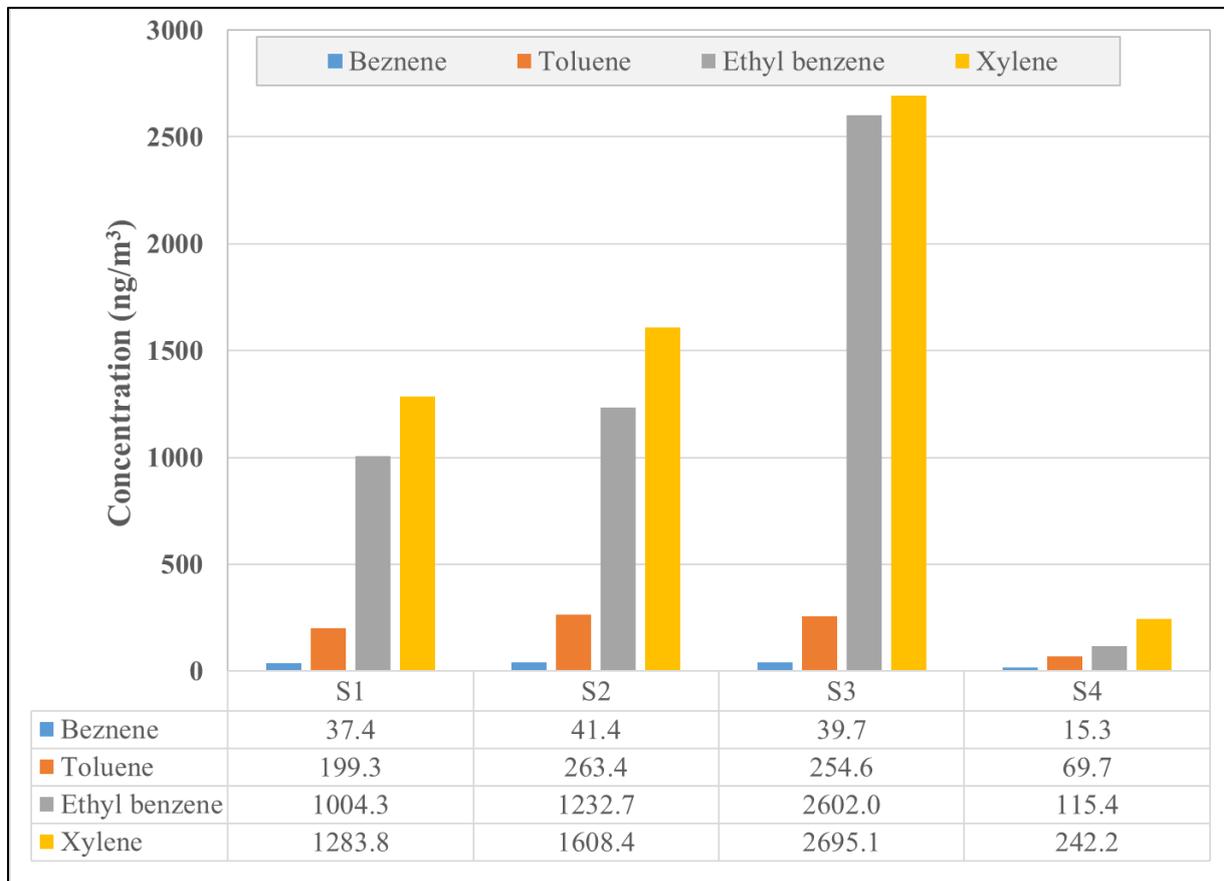


Figure 18: The seasonal mean concentrations of SO<sub>2</sub> and NO<sub>2</sub> observed at four sampling sites in Bhubaneswar region during the winter season sampling period (December 12 to 27, 2022)

Fig. 19, represents the seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX), observed at four sampling locations in Bhubaneswar region, during the winter season sampling period i.e. December 12 to 27, 2022. The winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites range from 15.3 to 41.4 ng/m<sup>3</sup>, 69.7 to 263.4 ng/m<sup>3</sup>, 115.4 to 2602.0 ng/m<sup>3</sup> and 242.2 to 2695.1 ng/m<sup>3</sup>, respectively. In general, the lowest concentrations were observed at RO Office, SPCB, Patia (S4) while the highest concentrations were observed at CIHETC, Jharpada (S3). It is important to note that, these VOC concentrations represent the general levels during the typical sampling period and may vary considerably during other time of day and/or season.



**Figure 19: The seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) observed at four sampling sites in Bhubaneswar region during the winter season sampling period (December 12 to 27, 2022)**

## **2.6.2. Summer season**

### **2.6.2.1. PM mass concentrations**

Fig. 20, presents the distribution of daily PM<sub>2.5</sub> and PM<sub>10</sub> concentrations observed at four sampling locations in Bhubaneswar region during the summer season i.e. Apr 11 – 29, 2023. The mean PM<sub>2.5</sub> and PM<sub>10</sub> mass concentrations during the entire sampling period over all sites were 43.3 and 93.8 µg/m<sup>3</sup>, respectively. The mean PM<sub>2.5</sub> concentrations exhibited a 5-fold range and ranged from a minimum of 16.2 µg/m<sup>3</sup> (at S2 i.e. OSPCB Head Office) to a maximum of 85.0 µg/m<sup>3</sup> (at S2 i.e. OSPCB Head Office). Similarly, the mean PM<sub>10</sub> concentrations exhibited a 6-fold range and ranged from 30.5 µg/m<sup>3</sup> (at S1 i.e. Gokhibaba Ashram) to 183.6 µg/m<sup>3</sup> (at S2 i.e. OSPCB Head Office).

The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 µg/m<sup>3</sup> for PM<sub>2.5</sub> and PM<sub>10</sub>, respectively. The summer-time PM<sub>2.5</sub> concentrations were observed to exceed the daily NAAQS limit at all sites (6 to 40%) with minimum exceedance at S3 i.e. Office of Chief Instructress Home Economic Training Centre (6%) and maximum at S2 i.e. OSPCB Head Office (40%). The daily averaged PM<sub>10</sub> concentrations exceeded the NAAQS limit at all sites (27-65%) with minimum exceedance at S1 i.e. Gokhibaba Ashram (27%) and maximum at S3 i.e. Office of Chief Instructress Home Economic Training Centre (65%).

### **2.6.2.2. Spatial variability**

The highest seasonal mean PM<sub>2.5</sub> concentrations were observed at at S2 i.e. OSPCB Head Office (48.5 µg/m<sup>3</sup>) while the lowest was recorded at S1 i.e. Gokhibaba Ashram (37.3 µg/m<sup>3</sup>). The PM<sub>2.5</sub> concentration showed highest and lowest variability at S2 i.e. OSPCB Head Office and S4 i.e. RO Office, respectively. For example, daily PM<sub>2.5</sub> concentrations ranged from 16.2 to 85.0 µg/m<sup>3</sup> at S2 i.e. OSPCB Head Office while it ranged from 16.9 to 81.2 µg/m<sup>3</sup> at S4 i.e. RO Office. This could be attributed to activities around the S2 i.e. OSPCB Head Office including, fugitive emissions, heavy duty traffic, and road dust re-suspension. S4 i.e. RO Office, SPCB.

The highest seasonal mean PM<sub>10</sub> concentrations were observed at S3 i.e. Office of Chief Instructress Home Economic Training Centre (117.5 µg/m<sup>3</sup>) while the lowest were recorded at S1 i.e. Gokhibaba Ashram (78.4 µg/m<sup>3</sup>). The PM<sub>10</sub> concentrations showed highest variability at S3 i.e. Office of Chief Instructress Home Economic Training Centre ranging from a

minimum of 48.5 to a maximum of 182.0  $\mu\text{g}/\text{m}^3$ . This could be attributed to fugitive emissions, road dust re-suspension due to movement of heavy vehicles in the region as well as summer time meteorological conditions (low RH and higher wind speed).

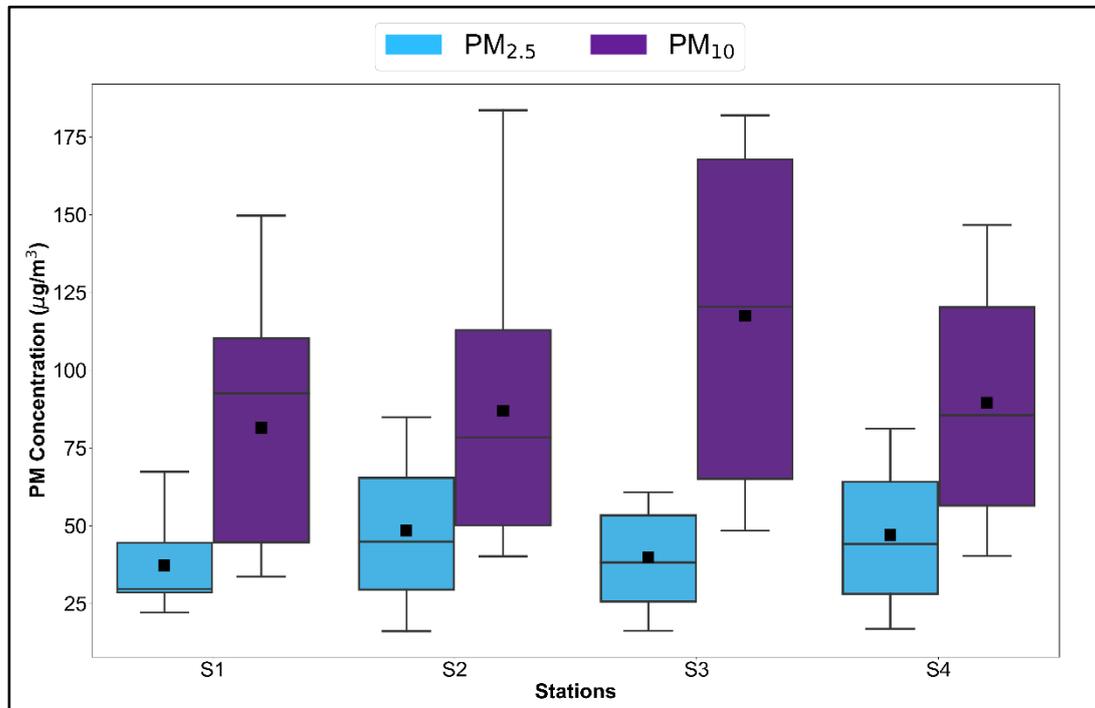


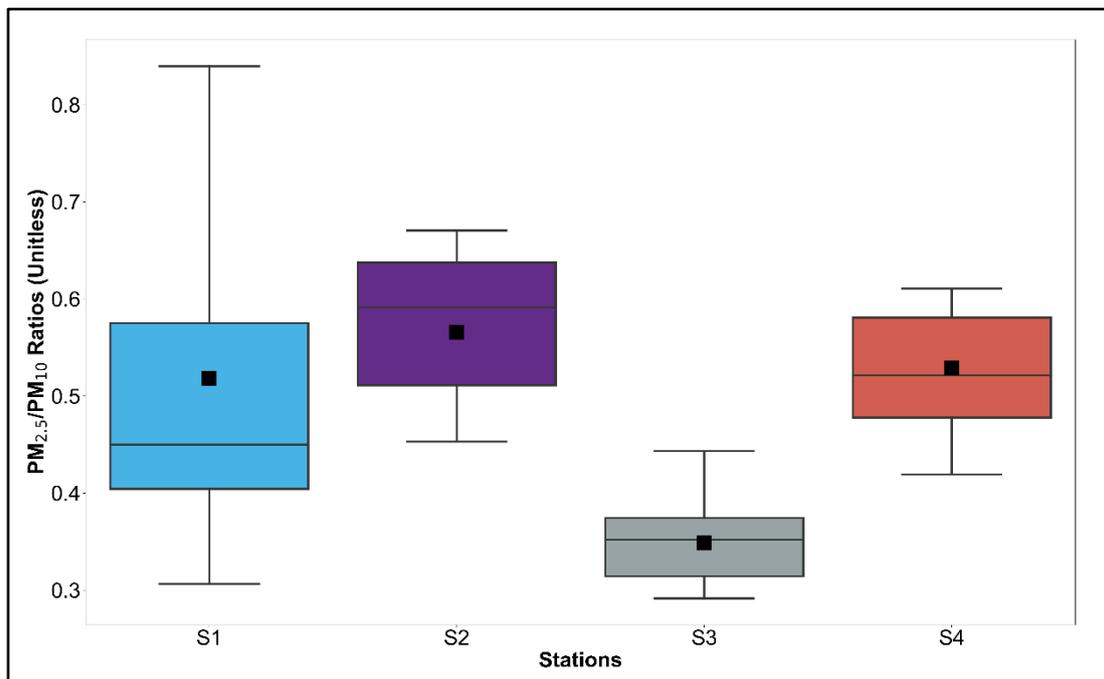
Figure 20 Boxplot showing distribution of daily PM<sub>2.5</sub> (blue colored boxes) and PM<sub>10</sub> (violet colored boxes) concentrations observed at four sampling sites in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023)

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range



#### 2.6.2.4. PM<sub>2.5</sub> to PM<sub>10</sub> ratios

Fig. 22 shows distribution of daily PM<sub>2.5</sub> to PM<sub>10</sub> ratios observed at four selected sites during the summer season sampling period (Apr 11 - 29, 2023). The average value of PM<sub>2.5</sub> to PM<sub>10</sub> ratios during the study period over all sites was found to be 0.49, varying from 0.22 to 0.84. The highest summer season mean PM<sub>2.5</sub> to PM<sub>10</sub> ratio was observed at S1 i.e. Gokhibaba Ashram while the lowest was observed at S3 i.e. Office of Chief Instructress Home Economic Training Centre (0.22). This variability in fine and coarse mode particles may be attributed to variability in PM chemical composition, which is in turn affected by various sources and meteorological conditions.



*Figure 22 Boxplot showing distribution of PM<sub>2.5</sub> to PM<sub>10</sub> ratios at four selected sites in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023)*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentile concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

### 2.6.2.5. Chemical composition of PM<sub>2.5</sub> and PM<sub>10</sub>

#### 2.6.2.5.1. Site 1: Gokhibaba Ashram

Fig. 23 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Ca<sup>++</sup>, Mg<sup>++</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, and SO<sub>4</sub><sup>-</sup>) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in PM<sub>2.5</sub> and PM<sub>10</sub> observed at S1 i.e. Gokhibaba Ashram site in Bhubaneswar region during the summer season (Apr 11 - 29, 2023). OC in PM<sub>2.5</sub> and OC, EC and SO<sub>4</sub><sup>-</sup> PM<sub>10</sub> are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m<sup>3</sup>. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

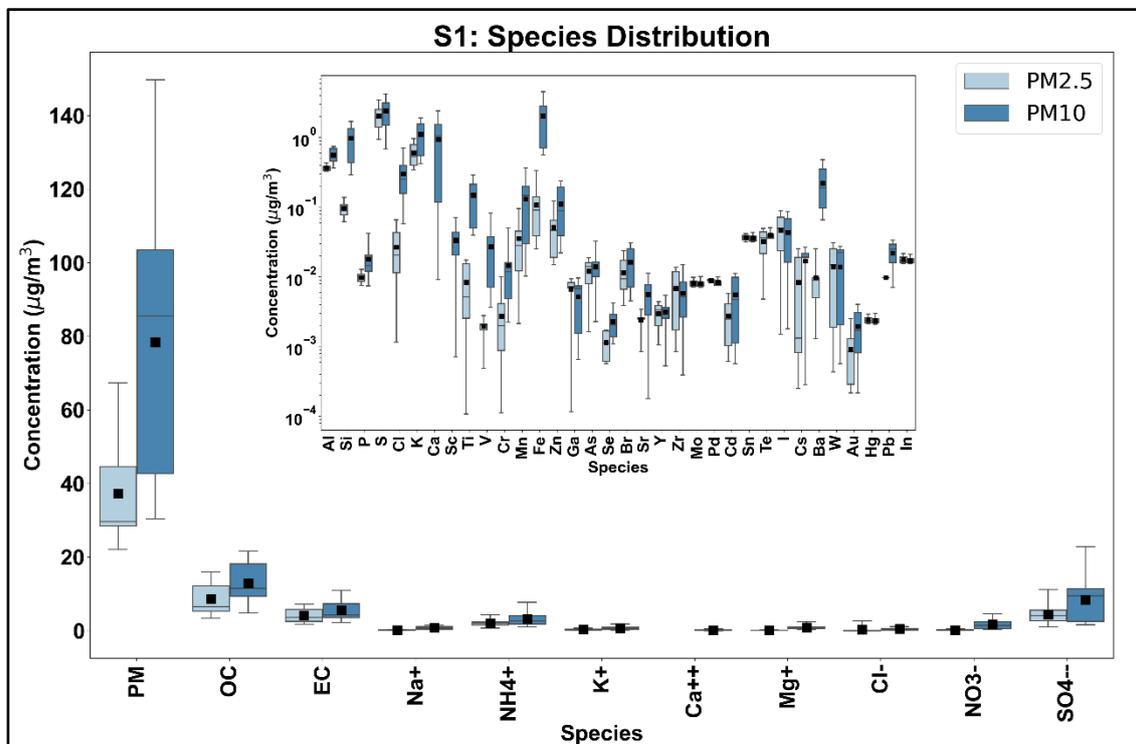
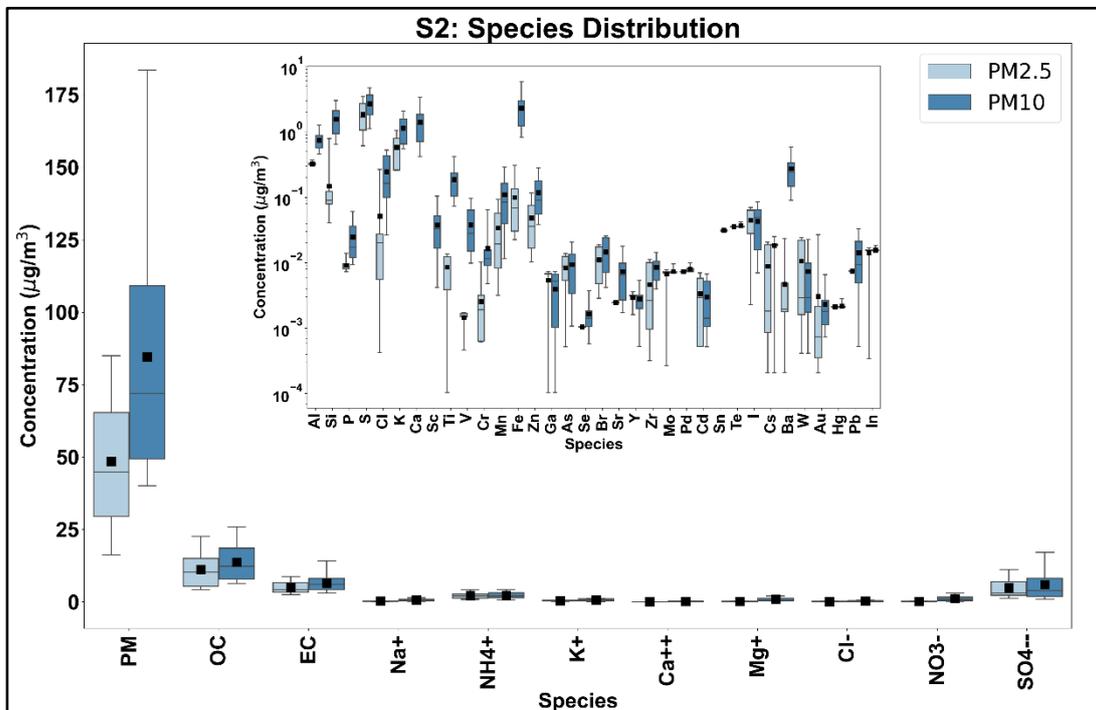


Figure 23 Box plots showing distribution of different species observed in PM<sub>2.5</sub> and PM<sub>10</sub> at S1 i.e. Gokhibaba Ashram in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023).

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

**2.6.2.5.2. Site 2: OSPCB Head Office**

Fig. 24 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions ( $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{--}$ ) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  observed at S2 i.e. OSPCB Head Office site in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023). OC and EC in  $\text{PM}_{2.5}$  and OC, EC and  $\text{SO}_4^{--}$  in  $\text{PM}_{10}$  are the most abundant species having seasonal mean concentrations greater than  $5.0 \mu\text{g}/\text{m}^3$ . Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.



*Figure 24 Box plots showing distribution of different species observed in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  at S2 i.e. OSPCB Head Office in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023)*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.5.3. Site 3: Office of Chief Instructress Home Economic Training Centre

Fig. 25 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions ( $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{--}$ ) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  observed at S3 i.e. Office of Chief Instructress Home Economic Training Centre in Bhubaneswar region during the summer season (Apr 11 - 29, 2023). OC and EC in  $\text{PM}_{2.5}$  while OC, EC and  $\text{SO}_4^{--}$ , in  $\text{PM}_{10}$  are the most abundant species having seasonal mean concentrations greater than  $5.0 \mu\text{g}/\text{m}^3$ . Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

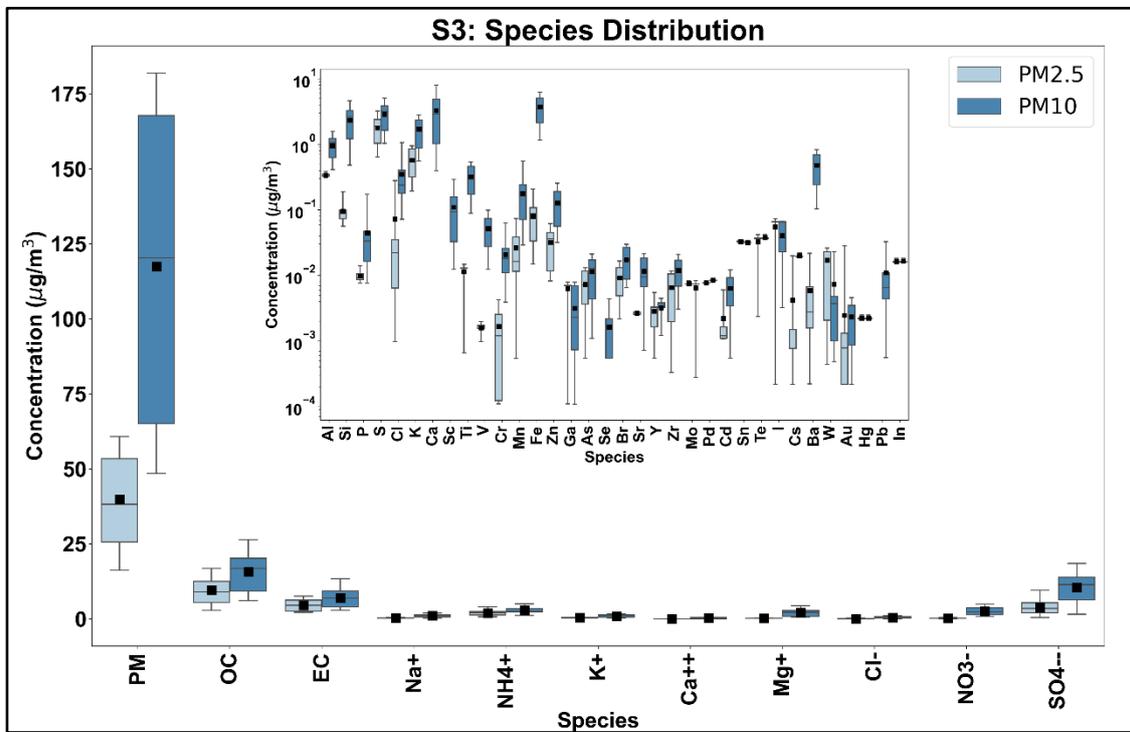


Figure 25 Box plots showing distribution of different species observed in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  at S3 i.e. Office of Chief Instructress Home Economic Training Centre in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023)

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.5.4. Site 4: RO Office, SPCB

Fig. 26 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions ( $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{--}$ ) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  observed at S4 i.e. RO Office, SPCB in Bhubaneswar region during the summer season (Apr 11 - 29, 2023). OC, EC and  $\text{SO}_4^{--}$  in  $\text{PM}_{2.5}$  and OC, EC, and  $\text{SO}_4^{--}$  in  $\text{PM}_{10}$  are the most abundant species having seasonal mean concentrations greater than  $5.0 \mu\text{g}/\text{m}^3$ . Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

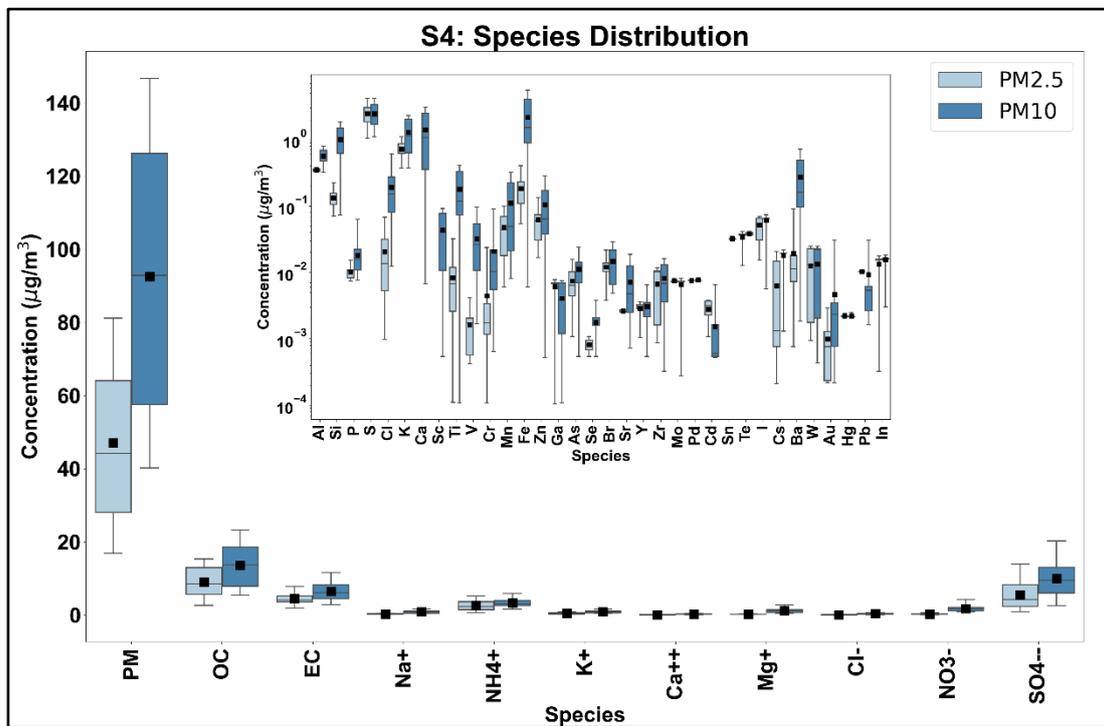
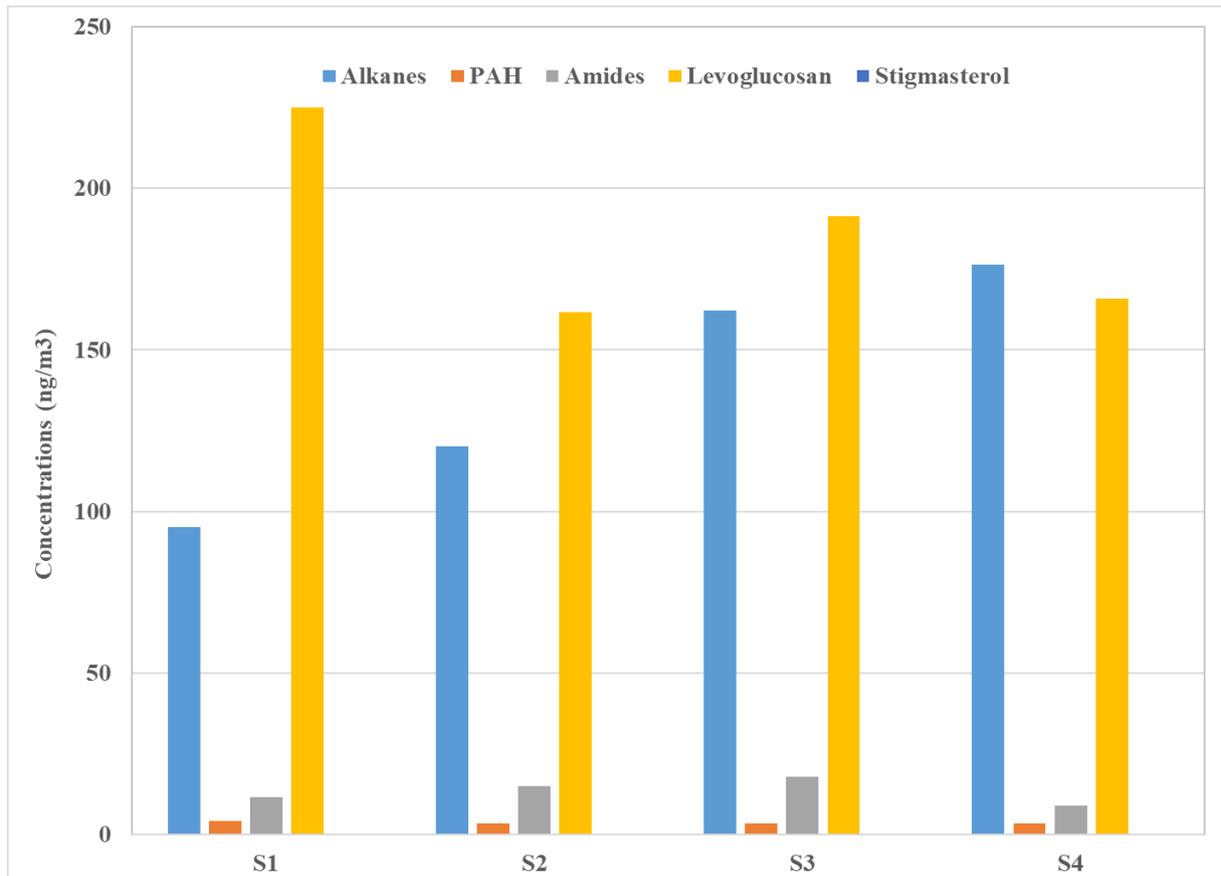


Figure 26 Box plots showing distribution of different species observed in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  at S4 i.e. RO Office, SPCB in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023)

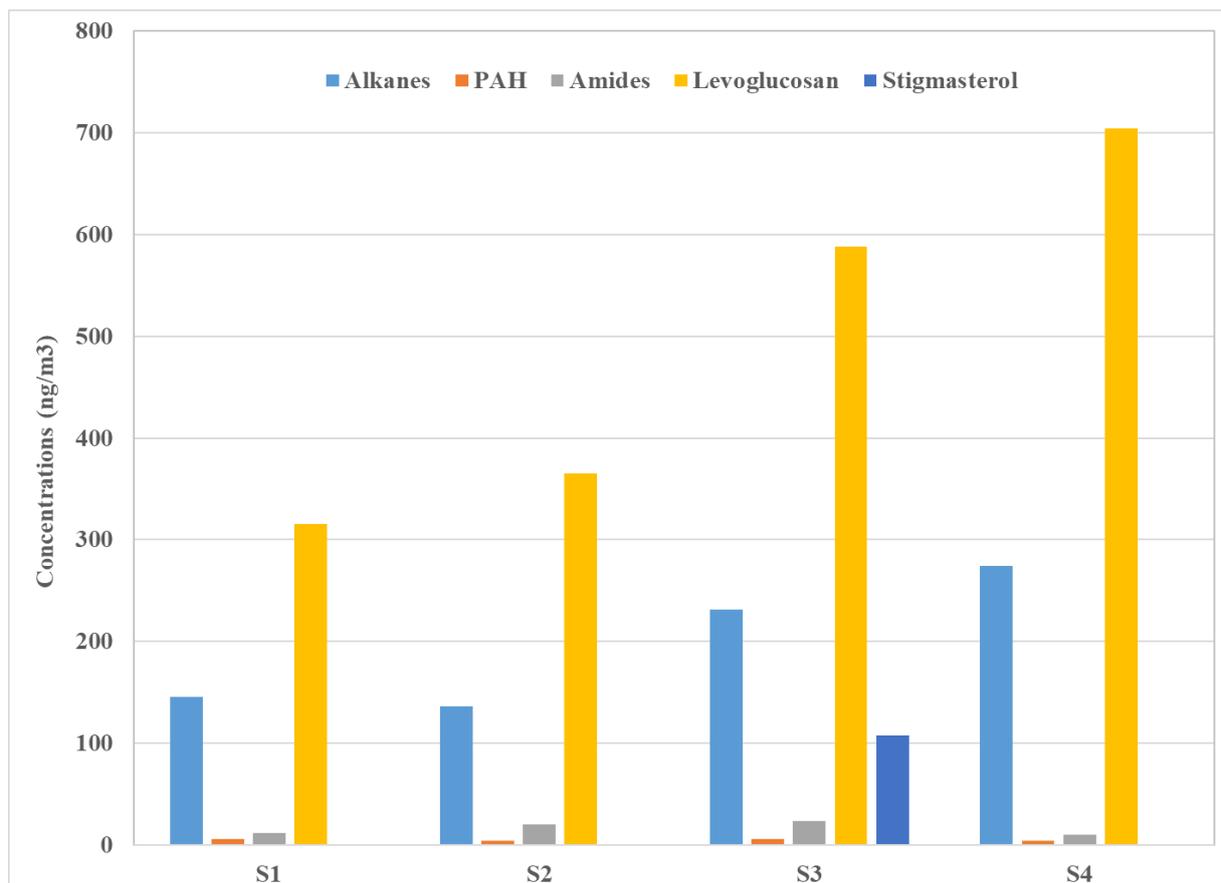
Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

### 2.6.2.6. Molecular Markers in PM<sub>2.5</sub> and PM<sub>10</sub>

Fig. 27, represents the seasonal mean concentrations of molecular markers observed at four sampling locations in Bhubaneswar region, during the summer season sampling period i.e. April 11 to 29, 2023. Levoglucosan is found to dominate the molecular markers mass, during the summer season. Levoglucosan is considered as a tracer for biomass burning emissions.



*Figure 27 The seasonal mean concentrations of molecular marker species in PM<sub>2.5</sub> (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023).*



*Figure 28 The seasonal mean concentrations of molecular marker species in PM<sub>10</sub> (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmaterol) observed at four sampling sites in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023).*

## 2.7. Mass reconstruction of Particulate Matter (PM<sub>2.5</sub> and PM<sub>10</sub>)

### 2.7.1. Validation of mass reconstruction methodology

As discussed in section 2.6.1.1, PM<sub>2.5</sub> and PM<sub>10</sub> mass concentrations were reconstructed. Fig. 29 and 30 shows the scatter plots of the 24-hour averaged reconstructed and gravimetric mass concentrations for the winter and summer season sampling duration, respectively. The reconstructed mass was significantly related to gravimetric mass in both winter and summer seasons. The squared correlation coefficient,  $R^2$  is found to be 0.80 (winter) and 0.89 (summer) for PM<sub>2.5</sub> whereas it is found to be 0.90 (winter) and 0.98 (summer) for PM<sub>10</sub>, respectively. These correlation coefficients are consistent with other published literature, with average values varying from 0.73 to 0.96 (Chow et al. 2015; Huang et al. 2014; 2017). In general, the PM<sub>Chem</sub> concentrations are less than those of PM<sub>Grav</sub> and the difference is defined as unknown. The

unknown mass could be attributed to: i) the water retained in the sampling membrane and particulate matter, ii) volatilization of organic matter and the decomposition of ammonium nitrate that may occur during the period between weighing and chemical measurements (Huang et al. 2017) and iii) uncertainties associated with conversion factors used in the estimation of metal oxides and OC to OM conversion (Cheung et al. 2011).

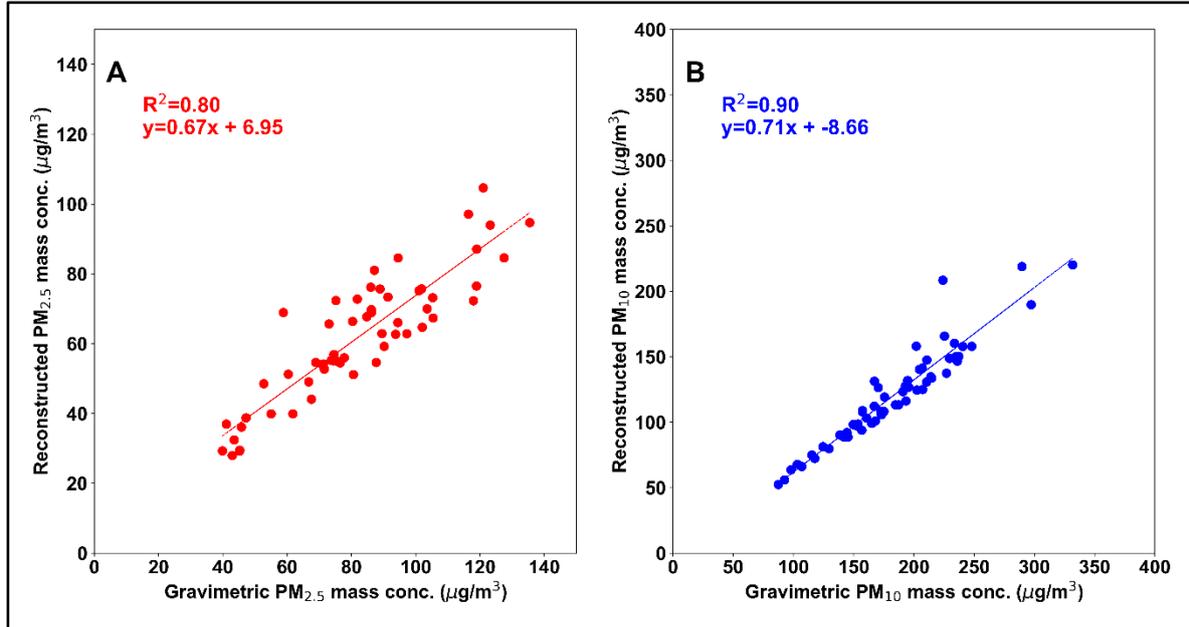


Figure 29 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) PM<sub>2.5</sub> and (B) PM<sub>10</sub> in Bhubaneswar region during the winter season sampling period (Dec 12 – 27, 2022)

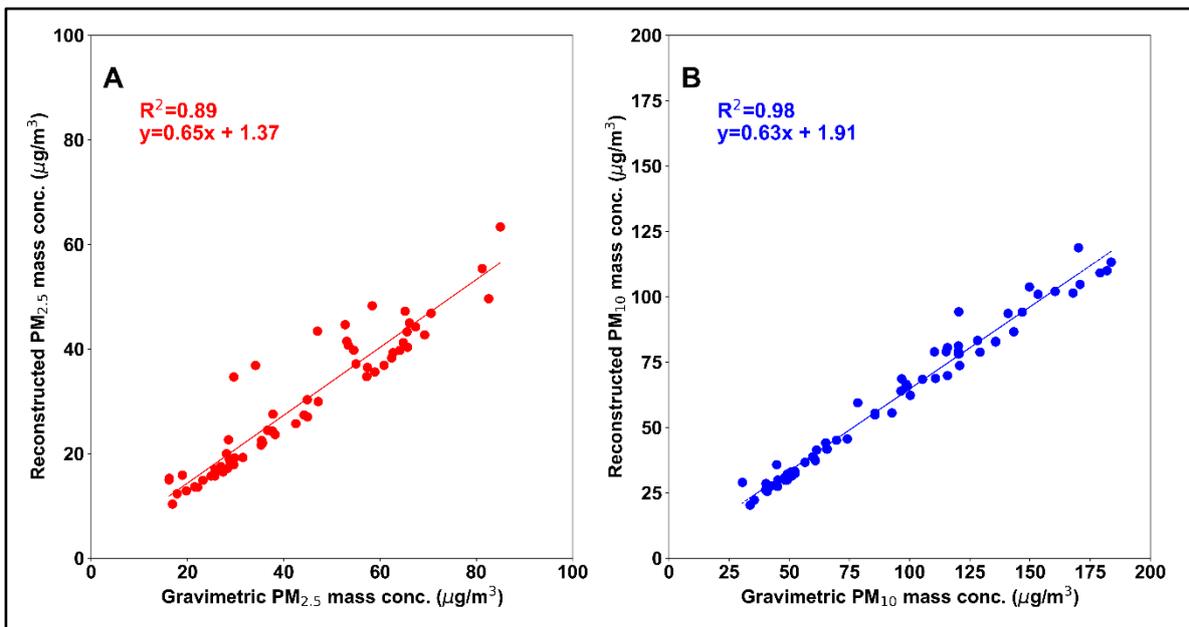


Figure 30 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) PM<sub>2.5</sub> and (B) PM<sub>10</sub> in Bhubaneswar region during the summer season sampling period (Apr 11 - 29, 2023)

### **2.7.2. Winter Season: Reconstructed chemical mass**

Fig. 31 to 34 and 35 to 38 presents the reconstructed chemical compositions of PM<sub>2.5</sub> and PM<sub>10</sub> during the winter season at four sampling locations in Bhubaneswar region, respectively. Overall, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in PM<sub>2.5</sub> whereas this order changed to OM > SNA > CM > EC > TE > SS in PM<sub>10</sub>.

The Organic mass (OM) was the most abundant component in PM<sub>2.5</sub> during the winter season, with seasonal mean contribution of 36.7 to 40.3% in PM<sub>2.5</sub> and 24.9 to 26.5% in PM<sub>10</sub>. The seasonal mean OM concentrations among the four sites in the winter season ranged from 30.3 to 32.6 µg/m<sup>3</sup> in PM<sub>2.5</sub> while it ranged from 44.79 to 49.24 µg/m<sup>3</sup> in PM<sub>10</sub>.

Secondary inorganic aerosols, represented as SNA, are the second major component observed in PM<sub>2.5</sub> and PM<sub>10</sub> fractions during the winter season in Bhubaneswar region. The seasonal mean contributions from SNA varied from 15.8 to 18.4% in PM<sub>2.5</sub> while it varied from 12.5 to 17.8% in PM<sub>10</sub>. The seasonal mean SNA concentrations among the four sites ranged from 13.2 to 14.3 µg/m<sup>3</sup> in PM<sub>2.5</sub> whereas it ranged from 22.6 to 32.4 µg/m<sup>3</sup> in PM<sub>10</sub>. The relative contributions indicate significant share of SNA in PM<sub>2.5</sub> during the winter season.

The seasonal mean contributions from EC ranged between 12.7 and 16.3% in PM<sub>2.5</sub> while it ranged between 9.3 and 10.7% in PM<sub>10</sub>. The seasonal mean elemental carbon (EC) concentrations during winter season varied from 10.5 to 14.1 µg/m<sup>3</sup> in PM<sub>2.5</sub> whereas it ranged from 16.3 to 21.2 µg/m<sup>3</sup> in PM<sub>10</sub>.

Crustal Mass (CM) is also an important contributor to coarse fraction i.e. PM<sub>10</sub> during winter season, besides OM and SNA. The seasonal mean contributions from CM varied from 2.3 to 3.1% in PM<sub>2.5</sub> while it varied from 12.5 to 13.4% in PM<sub>10</sub>. The seasonal mean CM concentrations in PM<sub>10</sub> varied from a minimum of 22.7 to 24.8 µg/m<sup>3</sup> in PM<sub>10</sub>. In contrast, the CM concentrations in fine fraction i.e. PM<sub>2.5</sub> were relatively lower and ranged from 1.9 to 2.7 µg/m<sup>3</sup>.

Trace elements (TE) also form an important part of the reconstructed mass in coarse fraction i.e. PM<sub>10</sub> during the winter season, with contributions ranging from 2.1 to 2.1%. The

seasonal mean TE concentrations ranged from 1.3 to 1.6  $\mu\text{g}/\text{m}^3$  and 3.6 to 3.9  $\mu\text{g}/\text{m}^3$  in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$ , respectively.

The Sea salt (SS) represented by a sum of  $\text{Na}^+$  and  $\text{Cl}^-$  ions, are the minor contributors to  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  masses during the winter season over Bhubaneswar, with contributions ranging from 0.7 to 1.0%. The seasonal mean SS ranged from 0.7 to 0.9  $\mu\text{g}/\text{m}^3$  in  $\text{PM}_{2.5}$  while it ranged from 1.2 to 2.0  $\mu\text{g}/\text{m}^3$  in  $\text{PM}_{10}$ .

The residual mass i.e. difference between the gravimetric and reconstructed mass, is defined as unidentified mass.

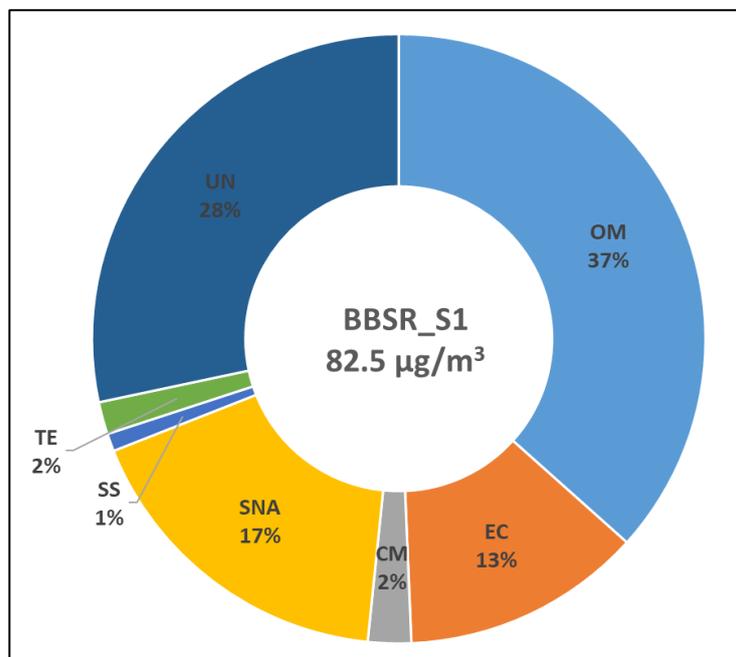


Figure 31: The reconstructed mass of  $\text{PM}_{2.5}$  at S1 i.e. Gokhibaba Ashram in Bhubaneswar region during the winter season

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

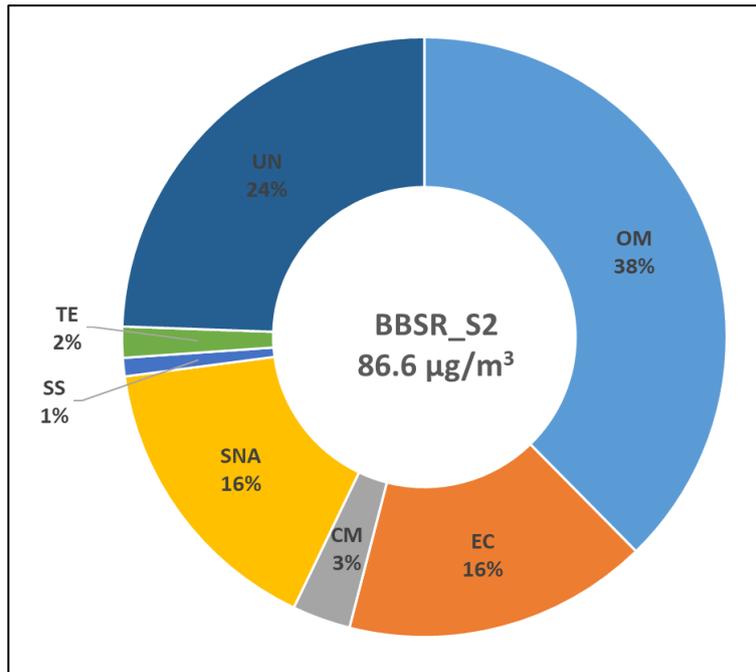


Figure 32: The reconstructed mass of PM<sub>2.5</sub> at S2 i.e. OSPCB Head Office in Bhubaneswar region during the winter season

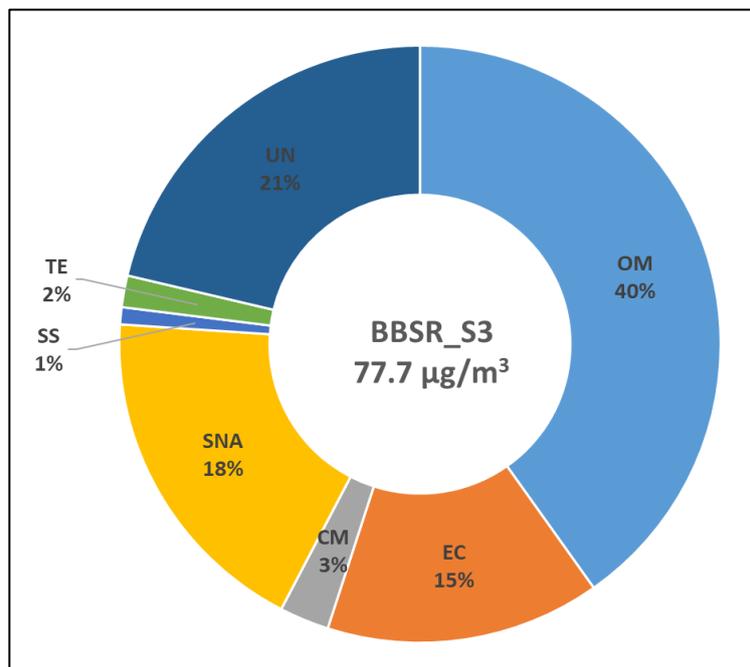


Figure 33: The reconstructed mass of PM<sub>2.5</sub> at S3 i.e. Office of Chief Instructress Home Economic Training Centre in Bhubaneswar region during the winter season

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

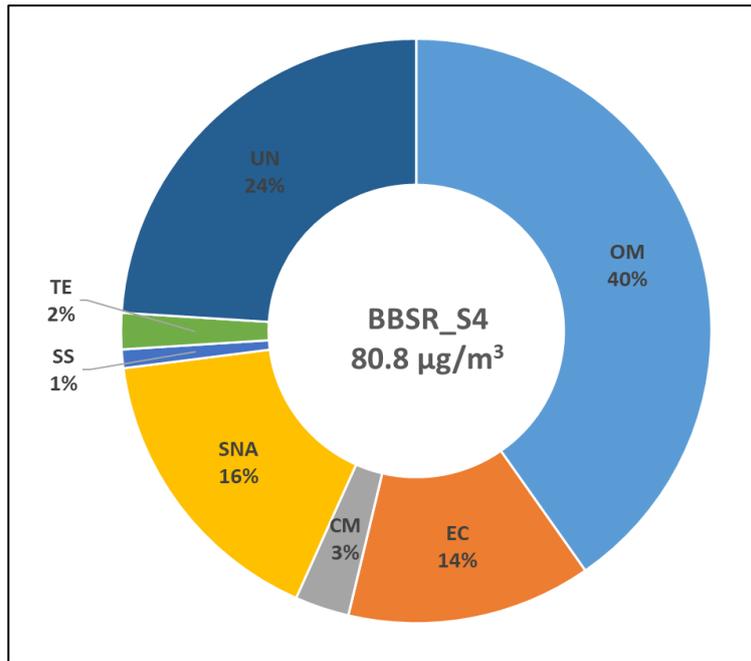


Figure 34: The reconstructed mass of  $PM_{2.5}$  at S4 i.e. RO Office, SPCB in Bhubaneswar region during the winter season

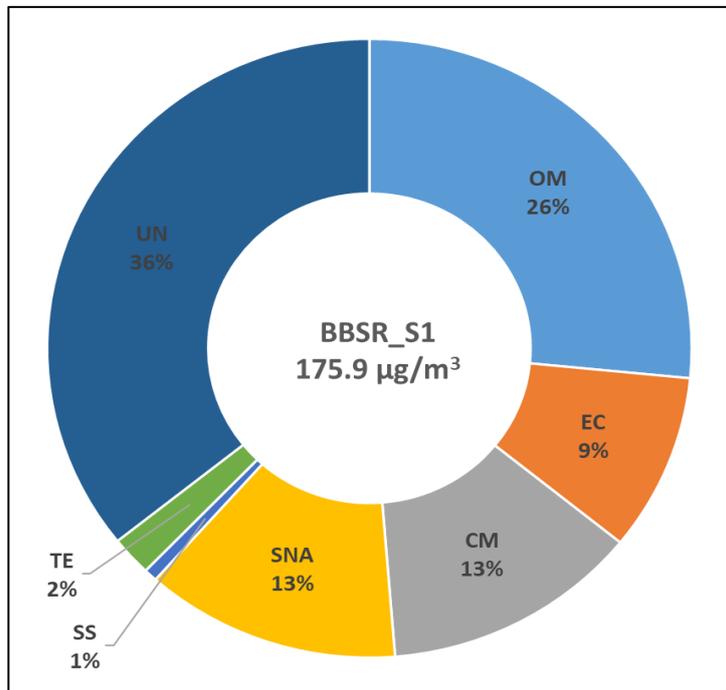


Figure 35: The reconstructed mass of  $PM_{10}$  at S1 i.e. Gokhibaba Ashram in Bhubaneswar region during the winter season.

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

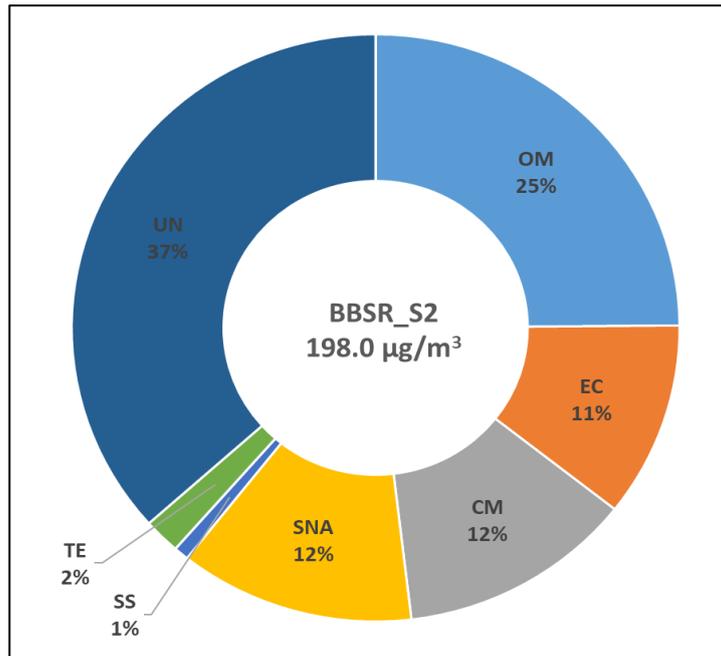


Figure 36: The reconstructed mass of PM<sub>10</sub> at S2 i.e. OSPCB Head Office in Bhubaneswar region during the winter season

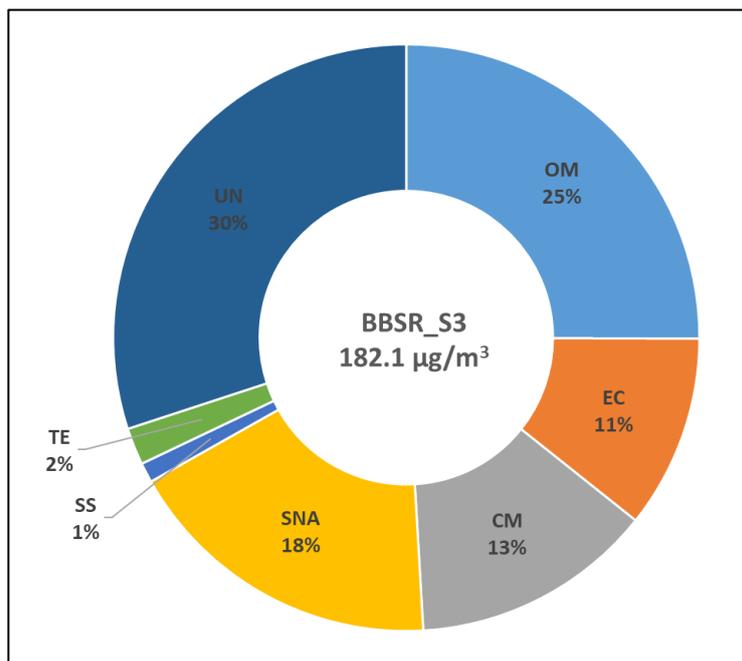
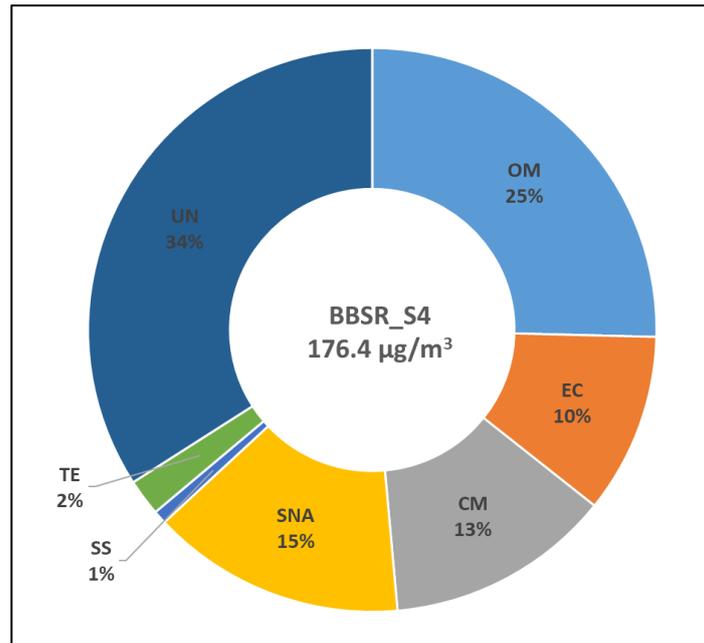


Figure 37: The reconstructed mass of PM<sub>10</sub> at S3 i.e. Office of Chief Instructress Home Economic Training Centre in Bhubaneswar region during the winter season

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.



*Figure 38: The reconstructed mass of PM<sub>10</sub> at S4 i.e. RO Office, SPCB in Bhubaneswar region during the winter season.*

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

### **2.7.3. Summer Season: Reconstructed chemical mass**

Fig. 39 to 42 and 43 to 46 presents the reconstructed chemical compositions of PM<sub>2.5</sub> and PM<sub>10</sub> during the summer season at four sampling locations in Bhubaneswar region, respectively. Overall, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in PM<sub>2.5</sub> whereas this order changed to OM > CM > SNA > EC > TE > SS in PM<sub>10</sub>.

The Organic mass (OM) was the most abundant component in both PM<sub>2.5</sub> and PM<sub>10</sub> during the summer season, with seasonal mean contribution of 30.5 to 38.3% in PM<sub>2.5</sub> and 21.5 to 26.4%. The seasonal mean OM concentrations in the summer season ranged from 13.9 to 17.8 µg/m<sup>3</sup> in PM<sub>2.5</sub> while it ranged from 20.7 to 25.2 µg/m<sup>3</sup> in PM<sub>10</sub>.

Secondary inorganic aerosols, represented as SNA, is the most important component observed in PM<sub>2.5</sub> and PM<sub>10</sub> fractions during the summer season in Bhubaneswar region, respectively. The seasonal mean contributions from SNA varied from 14.7 to 18.0% in PM<sub>2.5</sub> while it varied from 10.8 to 16.8% in PM<sub>10</sub>. The seasonal mean SNA concentrations ranged from 6.0 to 8.4 µg/m<sup>3</sup> in PM<sub>2.5</sub> whereas it ranged from 9.2 to 15.9 µg/m<sup>3</sup> in PM<sub>10</sub>. The relative contributions indicate significant share of SNA in PM<sub>2.5</sub> during the summer season.

The seasonal mean contributions from EC ranged between 9.5 and 11.4% in PM<sub>2.5</sub> while it ranged between 6.0 and 7.7% in PM<sub>10</sub>. The daily averaged elemental carbon (EC) concentrations during summer season varied from 4.2 to 5.0 µg/m<sup>3</sup> in PM<sub>2.5</sub> whereas it ranged from 5.6 to 7.0 µg/m<sup>3</sup> in PM<sub>10</sub>.

Crustal Mass (CM) is another important contributor to coarse fraction i.e. PM<sub>10</sub> during summer season. The seasonal mean contributions from CM varied from 2.6 to 3.6% in PM<sub>2.5</sub> while it varied from 13.4 to 19.5% in PM<sub>10</sub>. The seasonal mean CM concentrations in PM<sub>10</sub> varied from a minimum of 10.5 to 22.9 µg/m<sup>3</sup> in PM<sub>10</sub>. In contrast, the CM concentrations in fine fraction i.e. PM<sub>2.5</sub> were relatively lower and ranged from 1.2 to 1.5 µg/m<sup>3</sup>.

Trace elements (TE) form an important part of the reconstructed mass in coarse fraction i.e. PM<sub>10</sub> during the summer season, with contributions ranging from 2.3 to 2.5%. The seasonal

mean TE concentrations ranged from 0.8 to 0.9  $\mu\text{g}/\text{m}^3$  and 1.9 to 2.9  $\mu\text{g}/\text{m}^3$  in  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$ , respectively.

The Sea salt (SS) represented by a sum of  $\text{Na}^+$  and  $\text{Cl}^-$  ions, are the minor contributors to  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  masses during the summer season over Bhubaneswar region, with contributions ranging from 0.4 to 0.5%. The seasonal mean SS ranged from 0.4 to 0.5  $\mu\text{g}/\text{m}^3$  in  $\text{PM}_{2.5}$  while it ranged from 0.8 to 1.5  $\mu\text{g}/\text{m}^3$  in  $\text{PM}_{10}$ .

The residual mass i.e. difference between the gravimetric and reconstructed mass, is defined as unidentified mass.

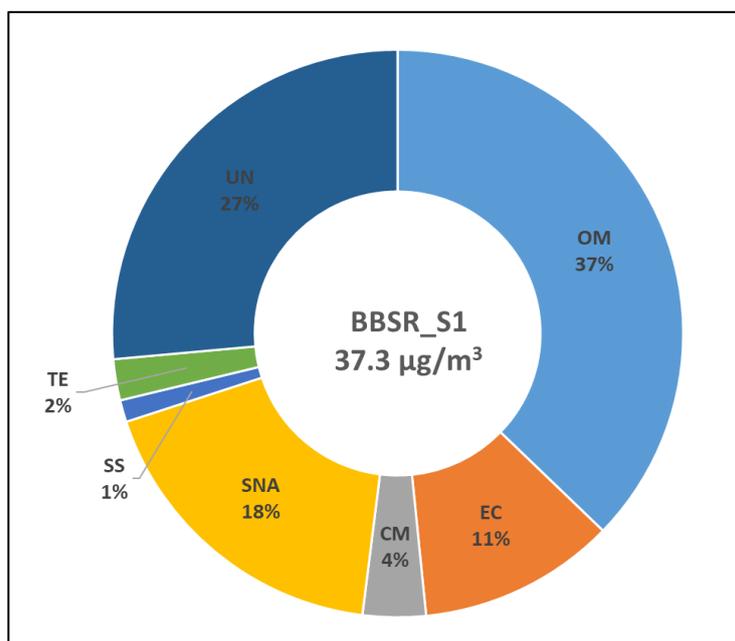


Figure 39: The reconstructed mass of  $\text{PM}_{2.5}$  at S1 i.e. Gokhibaba Ashram in Bhubaneswar region during the summer season

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

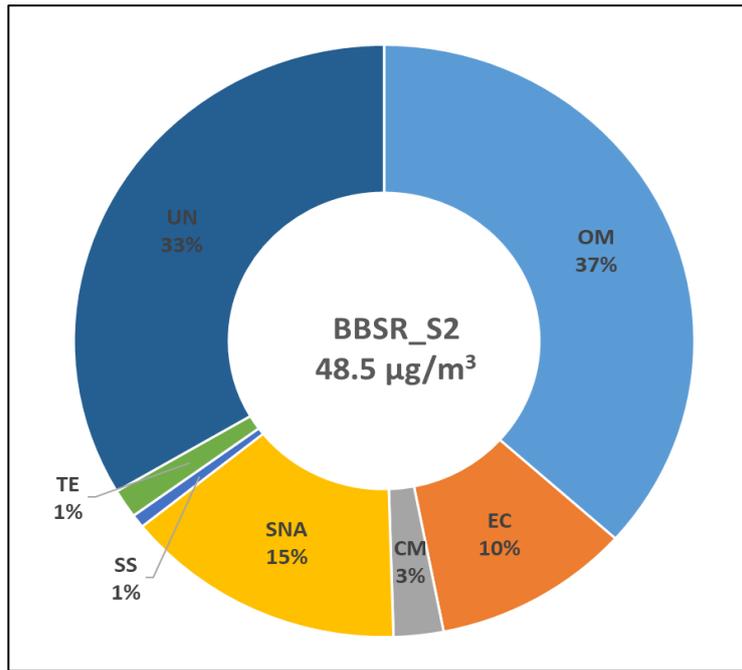


Figure 40: The reconstructed mass of PM<sub>2.5</sub> at S2 i.e. OSPCB Head Office in Bhubaneswar region during the summer season

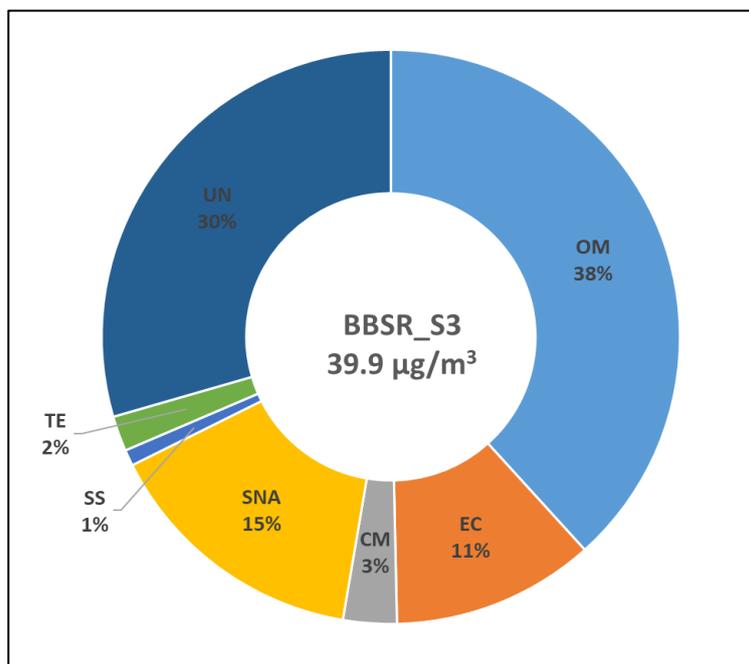


Figure 41: The reconstructed mass of PM<sub>2.5</sub> at S3 i.e. Office of Chief Instructress Home Economic Training Centre in Bhubaneswar region during the summer season

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

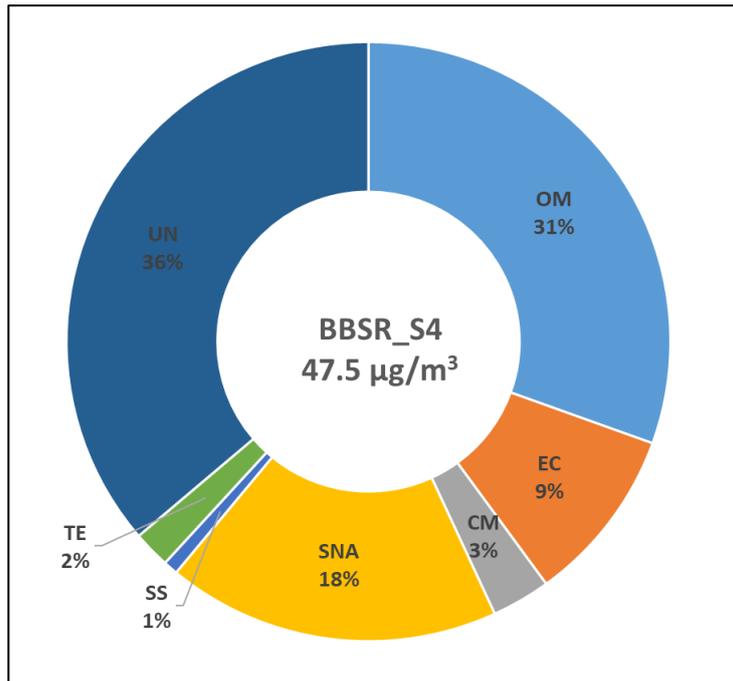


Figure 42: The reconstructed mass of  $PM_{2.5}$  at S4 i.e. RO Office, SPCB in Bhubaneswar region during the summer season

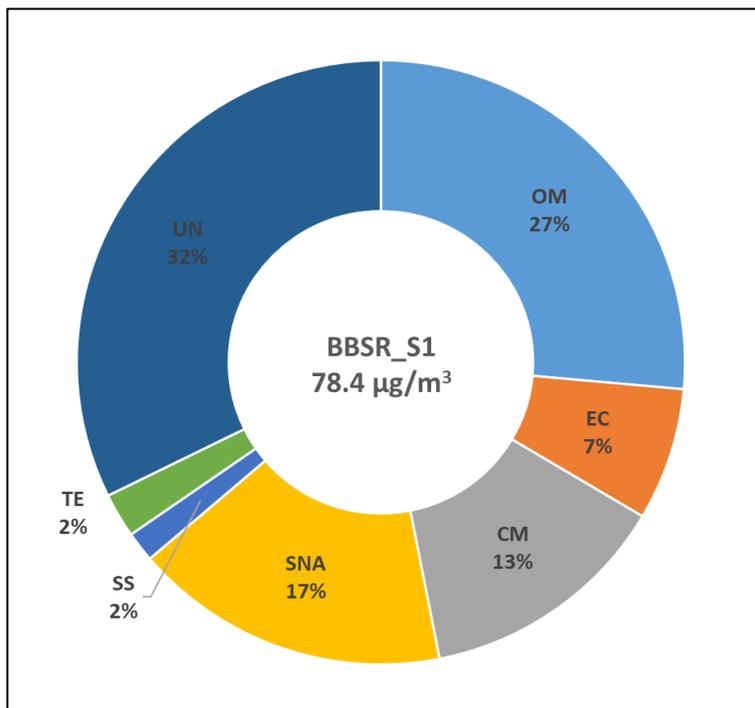


Figure 43: The reconstructed mass of  $PM_{10}$  at S1 i.e. Gokhibaba Ashram in Bhubaneswar region during the summer season.

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

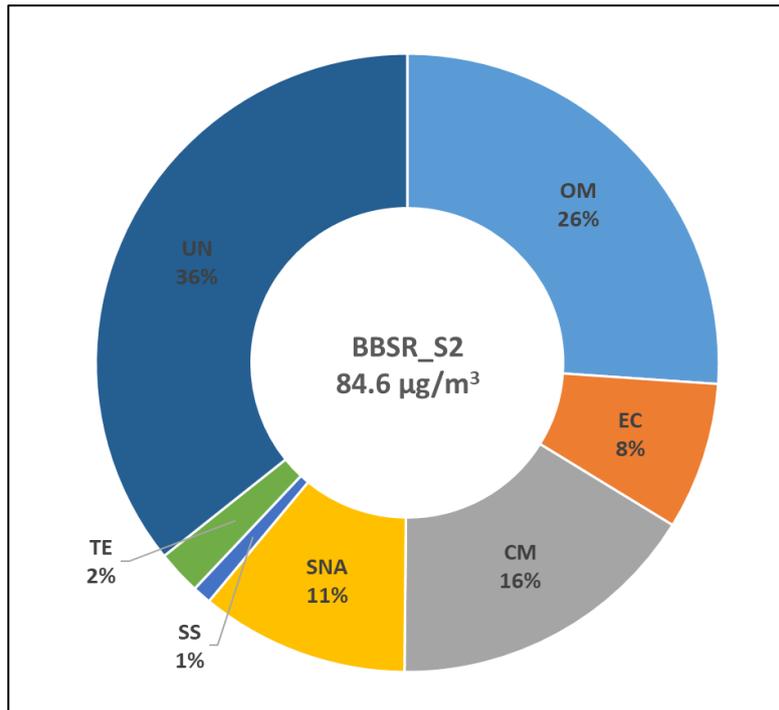


Figure 44: The reconstructed mass of  $PM_{10}$  at S2 i.e. OSPCB Head Office in Bhubaneswar region during the summer season

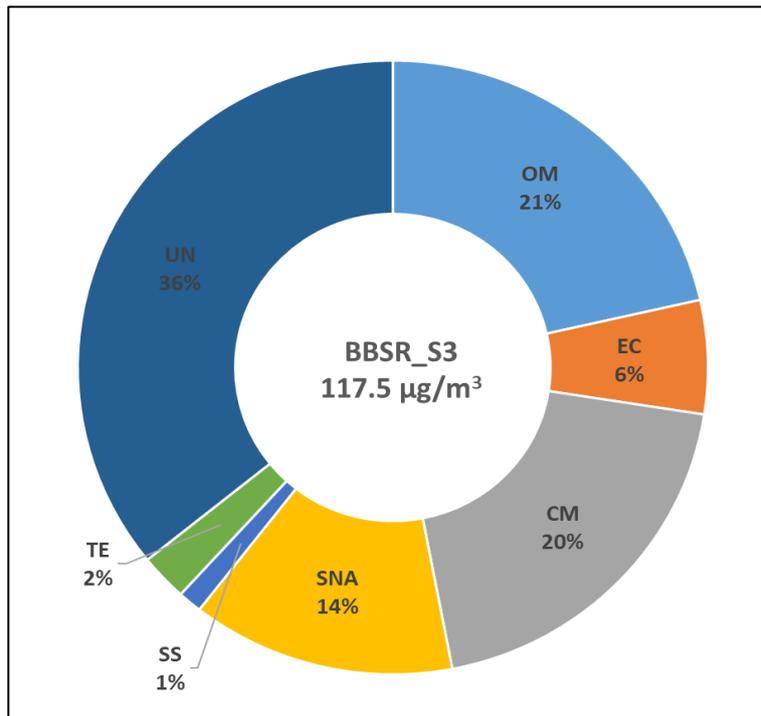
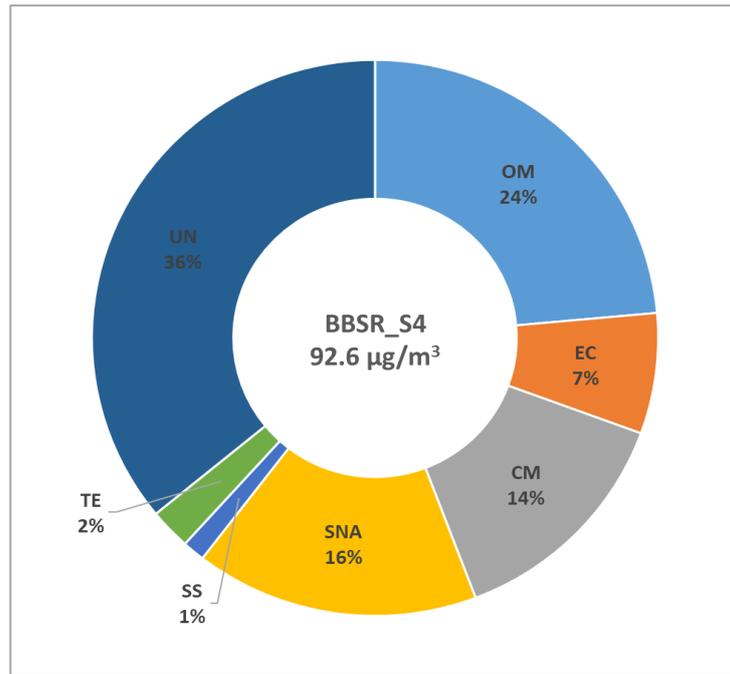


Figure 45: The reconstructed mass of  $PM_{10}$  at S3 i.e. Office of Chief Instructress Home Economic Training Centre in Bhubaneswar region during the summer season

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.



*Figure 46: The reconstructed mass of PM<sub>10</sub> at S4 i.e. RO Office, SPCB in Bhubaneswar region during the summer season.*

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

## **2.8. Chemical Ratios Analysis in PM<sub>2.5</sub> and PM<sub>10</sub>**

The chemical ratios of OC/EC, Cl<sup>-</sup>/Na<sup>+</sup>, K<sup>+</sup>/OC, K<sup>+</sup>/EC, NO<sub>3</sub><sup>-</sup>/SO<sub>4</sub><sup>-</sup> and degree of neutralization (DON) have been used as indicators to qualitatively assess the contributions from air polluting sources in the region and these ratios were calculated for our study sites. Fig. 47 (A) and (B) shows the chemical ratios i.e. i) OC to EC ratio, ii) Cl<sup>-</sup> to Na<sup>+</sup> ratio, iii) K<sup>+</sup> to OC ratio, iv) K<sup>+</sup> to EC, v) NO<sub>3</sub><sup>-</sup> to SO<sub>4</sub><sup>-</sup> ratio, and vi) degree of neutralization (DON) in PM<sub>2.5</sub> and PM<sub>10</sub> observed at four sampling locations in Bhubaneswar region during the winter and summer seasons, respectively. Table 3 provides summary of average chemical ratios.

The OC/EC ratio indicate the origins of carbonaceous fraction (Salameh et al. 2014) and is commonly used to assess the impacts of fossil fuel emissions and aging, and the formation of secondary organic aerosols (Niu et al. 2016). The average OC/EC ratio in the present study is close to 2, indicates that carbonaceous fraction is originated from primary sources during the both winter and summer seasons. A good correlation ( $R > 0.8$ ) is observed between OC and EC in both PM<sub>2.5</sub> and PM<sub>10</sub> at sampling sites implies their primary source signature (Srinivas and Sarin, 2014).

Soluble potassium (K<sup>+</sup>) concentrations were used to determine the possibility of contribution from biomass burning. Fossil fuel combustion seems to produce very little potassium and exhibit K<sup>+</sup>/OC and K<sup>+</sup>/EC ratios close to zero while other combustion sources such as biomass combustion and Savannah burning are characterized by K<sup>+</sup>/OC ratios ranging from 0.08 to 0.10 (Echalar et al. 1998) and from 0.04 to 0.13 (Andreae and Merlet 2001), respectively. Similarly, K<sup>+</sup>/EC ratios for biomass burning are reported to vary from 0.20 to 0.69 (Andreae 1983; Ram and Sarin 2010). The winter season K<sup>+</sup>/OC ratios ranged from 0.03 to 0.05 in PM<sub>2.5</sub> and PM<sub>10</sub>. Similarly, K<sup>+</sup>/EC ratios ranged from 0.06 to 0.09 in PM<sub>2.5</sub> and PM<sub>10</sub>. The summer season K<sup>+</sup>/OC ratios ranged from 0.04 to 0.07 in PM<sub>2.5</sub> and PM<sub>10</sub>. Similarly, K<sup>+</sup>/EC ratios ranged from 0.07 to 0.14 in PM<sub>2.5</sub> and PM<sub>10</sub>. These ratios suggest possibility of biomass burning in the region.

The NO<sub>3</sub><sup>-</sup>/SO<sub>4</sub><sup>-</sup> ratio has been used by researchers to assess the relative contributions from stationary versus mobile sources of PM (Arimoto et al. 1996). The winter-time NO<sub>3</sub><sup>-</sup>/SO<sub>4</sub><sup>-</sup> ratios varied from 0.43 to 0.47 in PM<sub>2.5</sub> whereas it varied from 0.69 to 0.78 PM<sub>10</sub>. Similarly, summer-time NO<sub>3</sub><sup>-</sup>/SO<sub>4</sub><sup>-</sup> ratios varied from 0.06 to 0.11 in PM<sub>2.5</sub> whereas it varied from 0.20 to 0.26 in PM<sub>10</sub>. Ratios less than unity indicates the dominance of stationary sources over mobile sources in Bhubaneswar region.

The average  $\text{Cl}^-/\text{Na}^+$  ratio of seawater is 1.8 and in general a ratio greater than 10, indicates anthropogenic origin of  $\text{Cl}^-$  ions. In the present study, the winter season mean  $\text{Cl}^-/\text{Na}^+$  ratio ranged from 1.51 to 2.19 in  $\text{PM}_{2.5}$  whereas it ranged from 2.34 to 3.41 in  $\text{PM}_{10}$ . The summer season mean  $\text{Cl}^-/\text{Na}^+$  ratio ranged from 0.26 to 2.39 in  $\text{PM}_{2.5}$  whereas it ranged from 0.41 to 0.57 in  $\text{PM}_{10}$ . The ratios less than 10 at all sites, indicate the natural origin of  $\text{Cl}^-$  ions such as marine aerosols.

Additionally, to understand the neutralization reactions in detail, Degree of Neutralization (DON) suggested by Adams et al. (1999) is calculated (refer Eq. 4) for daily  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  samples. In Eq. 5,  $[\text{NH}_4^+]$ ,  $[\text{SO}_4^{2-}]$  and  $[\text{NO}_3^-]$  represents the molar concentrations of ammonium, sulfate and nitrate ions, respectively observed over 24-h sampling. A  $\text{DON} < 1$  indicates an ammonium deficiency;  $\text{DON} = 1$  indicates complete neutralization whereas  $\text{DON} > 1$  indicates the presence of surplus ammonium in the atmosphere. It is important to note that, DON is a daily averaged value calculated from integrated 24-h filter-based samples, there are likely to be diurnal variations in the actual acidity of sulfate and nitrate particles.

$$\text{DON} = \frac{[\text{NH}_4^+]}{2[\text{SO}_4^{2-}] + [\text{NO}_3^-]} \dots \dots \dots \text{Eq. (5)}$$

In winter season, the average DON values ranged from 0.97 to 1.04 in  $\text{PM}_{2.5}$  and 0.74 to 0.82 in  $\text{PM}_{10}$  at four sampling locations in Bhubaneswar region. It shows the ammonium deficiency at all sites during the winter season, which in turn implies the slightly acidic nature of sulfate and nitrate particles. This could be explained by the persistent weak solar radiations, cold temperatures, and an obvious decoupling of high organic aerosol concentrations with acid particles, which in turn implies that the observed winter-time organics may be primary in nature (Chu et al., 2004).

In summer season, the average DON values ranged from 1.18 to 1.52 in  $\text{PM}_{2.5}$  and 0.73 to 1.23 in  $\text{PM}_{10}$  at four sampling locations in Bhubaneswar region. It shows the presence of sufficient and/or excess ammonium during the summer season, which in turn implies the neutral and/or basic nature of sulfate and nitrate particles. This could be attributed to increased ammonia emissions and higher temperatures leading to enhanced photochemical reactions during the summer season.

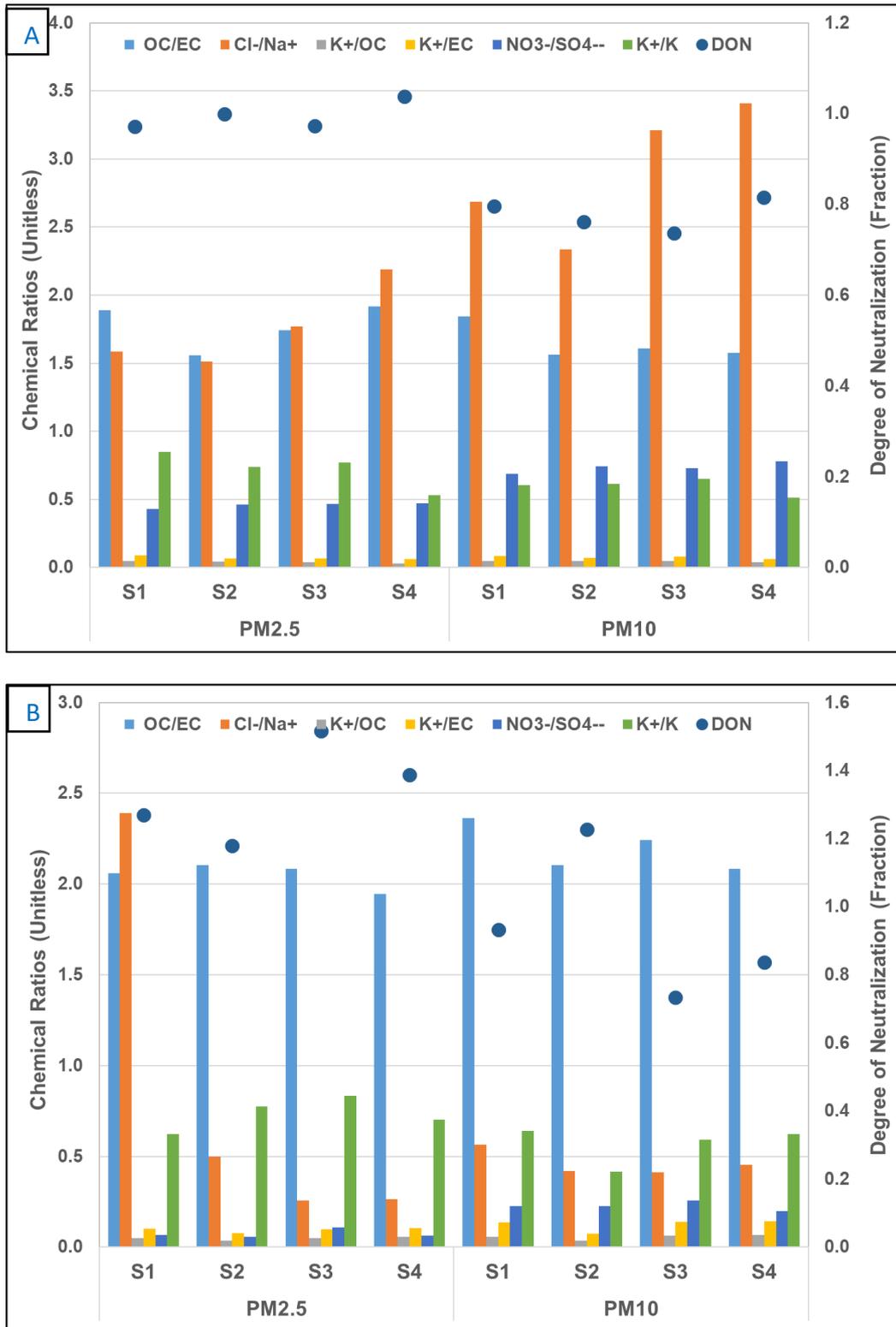


Figure 47: Chemical ratios i.e. OC to EC ratio, Cl<sup>-</sup> to Na<sup>+</sup> ratio, K<sup>+</sup> to OC ratio, K<sup>+</sup> to EC, NO<sub>3</sub><sup>-</sup> to SO<sub>4</sub><sup>2-</sup> ratio, and degree of neutralization (DON) observed at four sampling locations during the winter (A) and summer (B) seasons in Bhubaneswar region.

**Table 3 Summary of different chemical ratios observed at four sampling locations during the winter and summer seasons in Bhubaneswar region**

Fraction	Site	OC/EC	Cl <sup>-</sup> /Na <sup>+</sup>	K <sup>+</sup> /OC	K <sup>+</sup> /EC	NO <sub>3</sub> <sup>-</sup> / SO <sub>4</sub> <sup>-</sup>	DON
Winter PM <sub>2.5</sub>	S1	1.89	1.59	0.05	0.09	0.43	0.97
	S2	1.56	1.51	0.04	0.06	0.46	1.00
	S3	1.74	1.77	0.04	0.07	0.47	0.97
	S4	1.92	2.19	0.03	0.06	0.47	1.04
Winter PM <sub>10</sub>	S1	1.84	2.69	0.05	0.09	0.69	0.80
	S2	1.56	2.34	0.05	0.07	0.74	0.76
	S3	1.61	3.21	0.05	0.08	0.73	0.74
	S4	1.58	3.41	0.04	0.06	0.78	0.82
Summer PM <sub>2.5</sub>	S1	2.06	2.39	0.05	0.10	0.07	1.27
	S2	2.10	0.50	0.04	0.08	0.06	1.18
	S3	2.08	0.26	0.05	0.10	0.11	1.52
	S4	1.94	0.27	0.06	0.11	0.06	1.39
Summer PM <sub>10</sub>	S1	2.36	0.57	0.06	0.13	0.23	0.93
	S2	2.10	0.42	0.04	0.07	0.23	1.23
	S3	2.24	0.41	0.06	0.14	0.26	0.73
	S4	2.08	0.46	0.07	0.14	0.20	0.84

## 2.9. Source apportionment of PM<sub>2.5</sub> and PM<sub>10</sub>

Source contributions to fine and coarse particulate matter i.e. PM<sub>2.5</sub> and PM<sub>10</sub> were calculated with the CMB model for the individual daily samples for four sampling sites in Bhubaneswar region. Five pollution sources were apportioned using the average concentration data including i) transport (TRAN), ii) road and construction dust (DUST), iii) biomass burning (BCOM), iv) industry and thermal powerplants and fugitive dust (INDU) and v) secondary aerosols (SECY). The residual/un-apportioned mass is considered to be originating from the unidentified sources (UNID).

## 2.9.1. WINTER SEASON

### 2.9.1.1. Site 1: Gokhibaba Ashram

Fig. 48 shows the sectoral source contributions to  $PM_{2.5}$  and  $PM_{10}$  at S1 i.e. Gokhibaba Ashram during winter season. The winter season mean modelled  $PM_{2.5}$  and  $PM_{10}$  concentrations at this site were  $82.5 \mu\text{g}/\text{m}^3$  and  $175.9 \mu\text{g}/\text{m}^3$ , respectively. The winter time  $PM_{2.5}$  mass was found to be dominated by transport with highest contribution of 33.8%. The other sources of  $PM_{2.5}$  at this site were identified as biomass and solid waste combustion (32.9%), secondary aerosols (15.0%), dusty sources (11.0%), and industry (1.0%). The winter-time  $PM_{10}$  concentrations at this site was found to be dominated by secondary aerosols (25.1%), followed by, dust (24.1%), secondary aerosols (21.2%), transport (20.1%), and industry (0.9%). About 6.2% and 8.7% in  $PM_{2.5}$  and  $PM_{10}$  mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

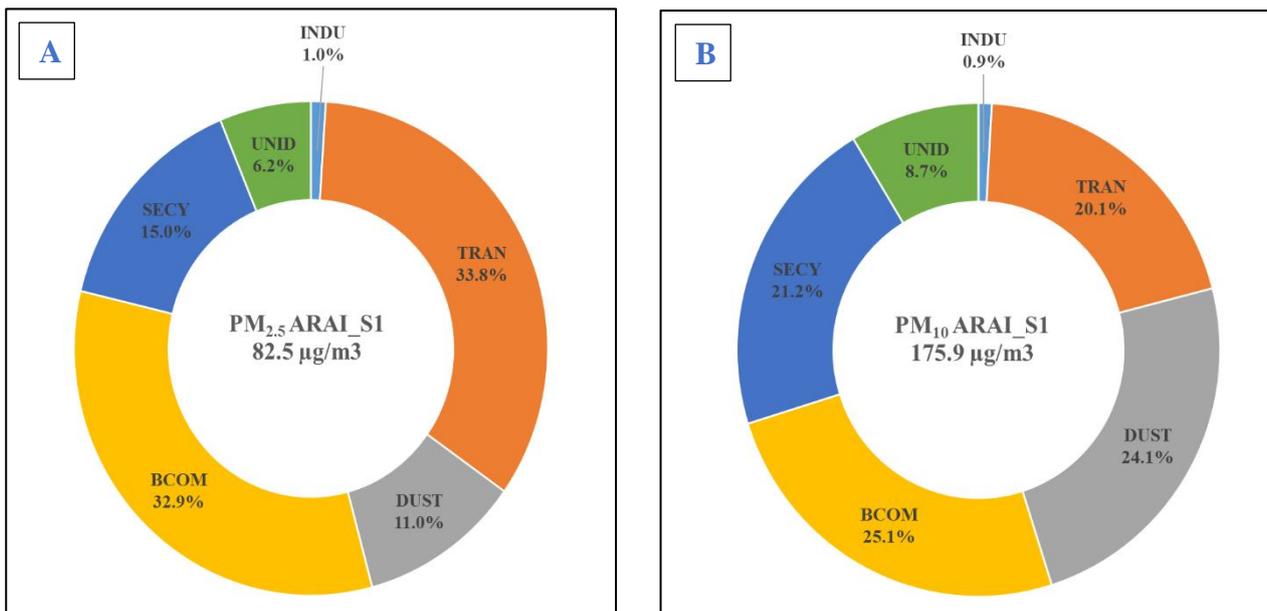


Figure 48 Sectoral source contributions to  $PM_{2.5}$  (A) and  $PM_{10}$  (B) at S1 i.e. Gokhibaba Ashram during the winter season in Bhubaneswar region

### 2.9.1.2. Site 2: OSPCB Head Office

Fig. 49 shows the sectoral source contributions to PM<sub>2.5</sub> and PM<sub>10</sub> at S2 i.e. OSPCB Head Office during winter season. The winter season mean modelled PM<sub>2.5</sub> and PM<sub>10</sub> concentrations at this site were 86.6 µg/m<sup>3</sup> and 198.0 µg/m<sup>3</sup>, respectively. The winter time PM<sub>2.5</sub> mass was found to be dominated by transport with highest contribution of 35.6%. The other sources of PM<sub>2.5</sub> at this site were identified as biomass and solid waste combustion (32.1%), secondary aerosols (13.4%), dust (12.7%), and industry (1.1%). The winter-time PM<sub>10</sub> concentrations at this site was dominated by dust Sources (27.1%), followed by biomass and solid waste combustion (22.3%), transport (21.4%), secondary aerosols (18.2%), and industry (1.2%). About 5.1% and 9.7% in PM<sub>2.5</sub> and PM<sub>10</sub> mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

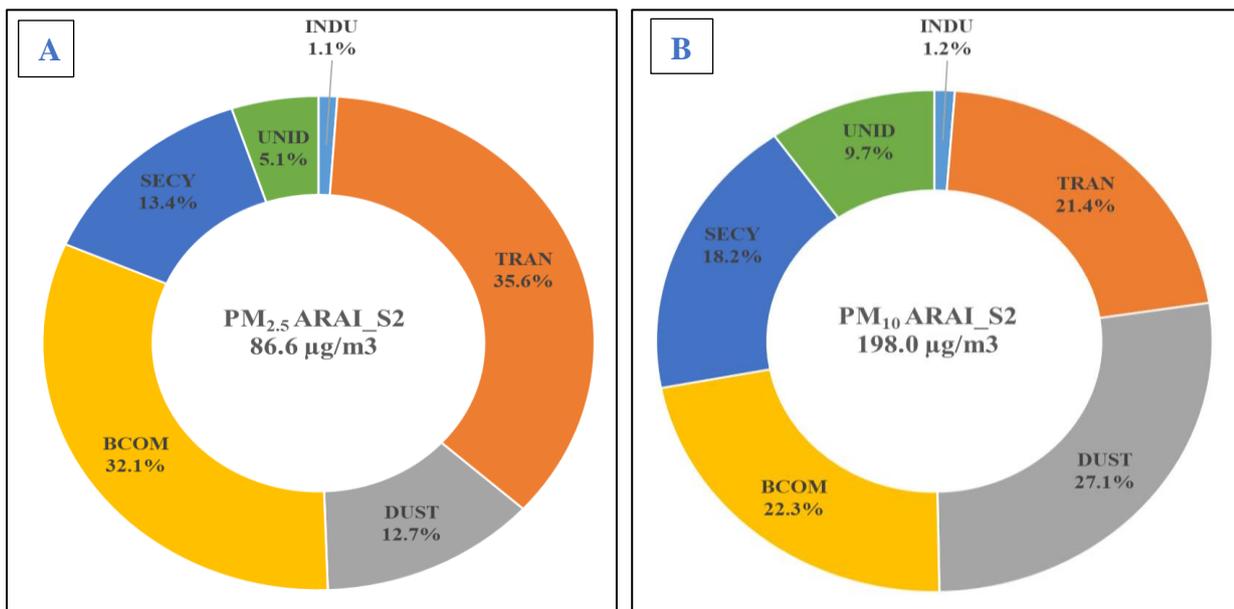


Figure 49 Sectoral source contributions to PM<sub>2.5</sub> (A) and PM<sub>10</sub> (B) at S2 i.e. OSPCB Head Office during winter season

### 2.9.1.3. Site 3: Office of Chief Instructress Home Economic Training Centre

Fig. 50 shows the sectoral source contributions to PM<sub>2.5</sub> and PM<sub>10</sub> at S3 i.e. Office of Chief Instructress Home Economic Training Centre during winter season. The winter season mean modelled PM<sub>2.5</sub> and PM<sub>10</sub> concentrations at this site were 77.7 µg/m<sup>3</sup> and 182.1 µg/m<sup>3</sup>, respectively. The winter time PM<sub>2.5</sub> mass was found to be dominated by biomass and solid waste combustion sources with highest contribution of 40.9%. The other sources of PM<sub>2.5</sub> at this site were identified as transport (31.9%), dust (10.9%), secondary aerosols (8.2%), and industry (1.0%). The winter-time PM<sub>10</sub> concentrations at this site were also dominated by biomass and solid waste combustion (32.7%), followed by dust (24.9%), transport (19.7%), secondary aerosols (12.0%), and industry (0.9%). About 7.1% and 9.7% in PM<sub>2.5</sub> and PM<sub>10</sub> mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

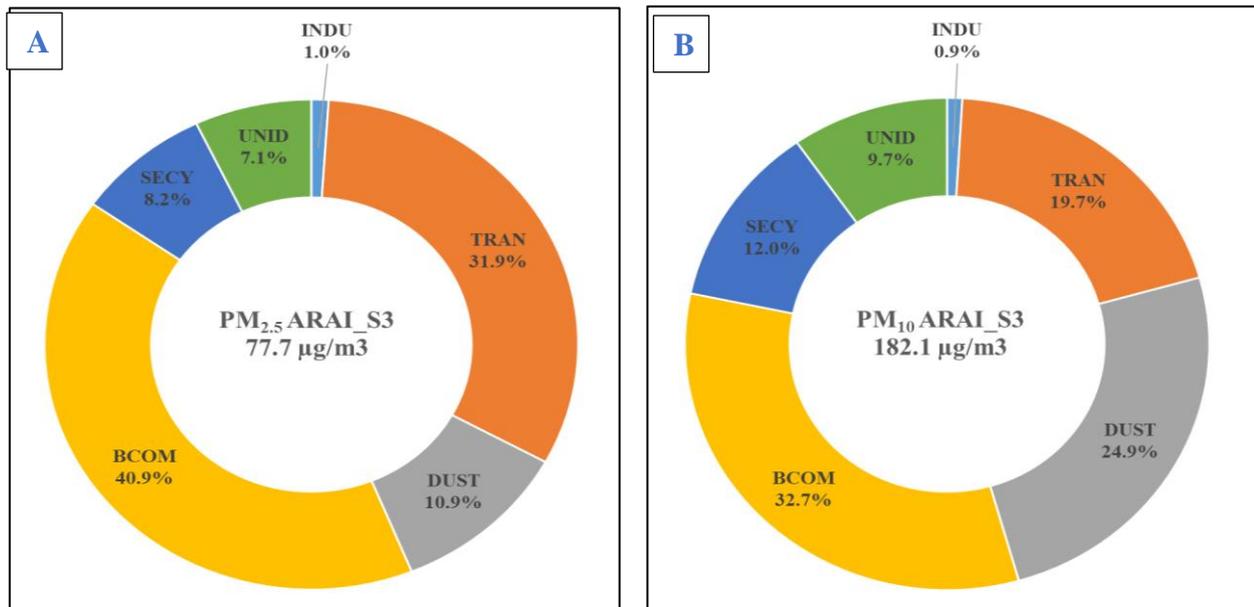


Figure 50 Sectoral source contributions to PM<sub>2.5</sub> (A) and PM<sub>10</sub> (B) at S3 i.e. Office of Chief Instructress Home Economic Training Centre during winter season

#### 2.9.1.4. Site 4: RO Office, SPCB

Fig. 51 shows the sectoral source contributions to  $PM_{2.5}$  and  $PM_{10}$  at S4 i.e. RO Office, SPCB site during winter season. The winter season mean modelled  $PM_{2.5}$  and  $PM_{10}$  concentrations at this site were  $80.8 \mu\text{g}/\text{m}^3$  and  $176.4 \mu\text{g}/\text{m}^3$ , respectively. The winter time  $PM_{2.5}$  mass was found to be dominated by biomass and solid waste combustion sources with highest contribution of 44.6%. The other sources of  $PM_{2.5}$  at this site were identified as transport (21.3%), secondary aerosols (12.6%), dust (7.3%), and industry (1.4%). The winter-time  $PM_{10}$  concentrations at this site were also dominated by biomass and solid waste combustion sources (36.2%), followed by secondary aerosols (19.4%), dust (16.7%), transport (13.2%), and industry (1.4%). About 12.7% and 13.0% in  $PM_{2.5}$  and  $PM_{10}$  mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

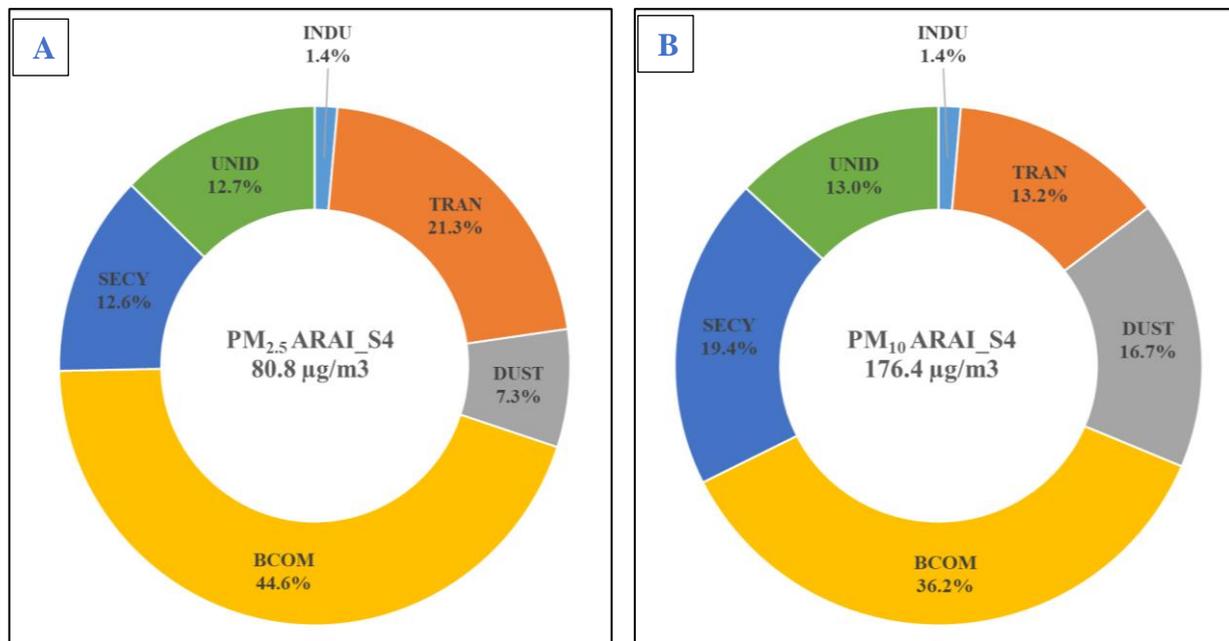


Figure 51 Sectoral source contributions to  $PM_{2.5}$  (A) and  $PM_{10}$  (B) at S4 i.e. RO Office, SPCB during winter season

## 2.9.2. SUMMMER SEASON

### 2.9.2.1. Site 1: Gokhibaba Ashram

Fig. 52 shows the sectoral source contributions to PM<sub>2.5</sub> and PM<sub>10</sub> at S1 i.e. Gokhibaba Ashram during summer season. The summer season mean modelled PM<sub>2.5</sub> and PM<sub>10</sub> concentrations at this site were 37.3 µg/m<sup>3</sup> and 78.4 µg/m<sup>3</sup>, respectively. The summer time PM<sub>2.5</sub> mass was found to be dominated by transport sources with highest contribution of 34.1%. The other sources of PM<sub>2.5</sub> at this site were identified as secondary aerosols (24.1%), biomass and solid waste combustion (20.5%), dust (15.1%), and industry (0.8%). The summer-time PM<sub>10</sub> concentrations at this site was dominated by secondary aerosols (30.2%), followed by, dust (26.5%), transport (18.4%), biomass and solid waste combustion (13.8%), industry (0.6%), and. About 5.4% and 10.6% in PM<sub>2.5</sub> and PM<sub>10</sub> mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

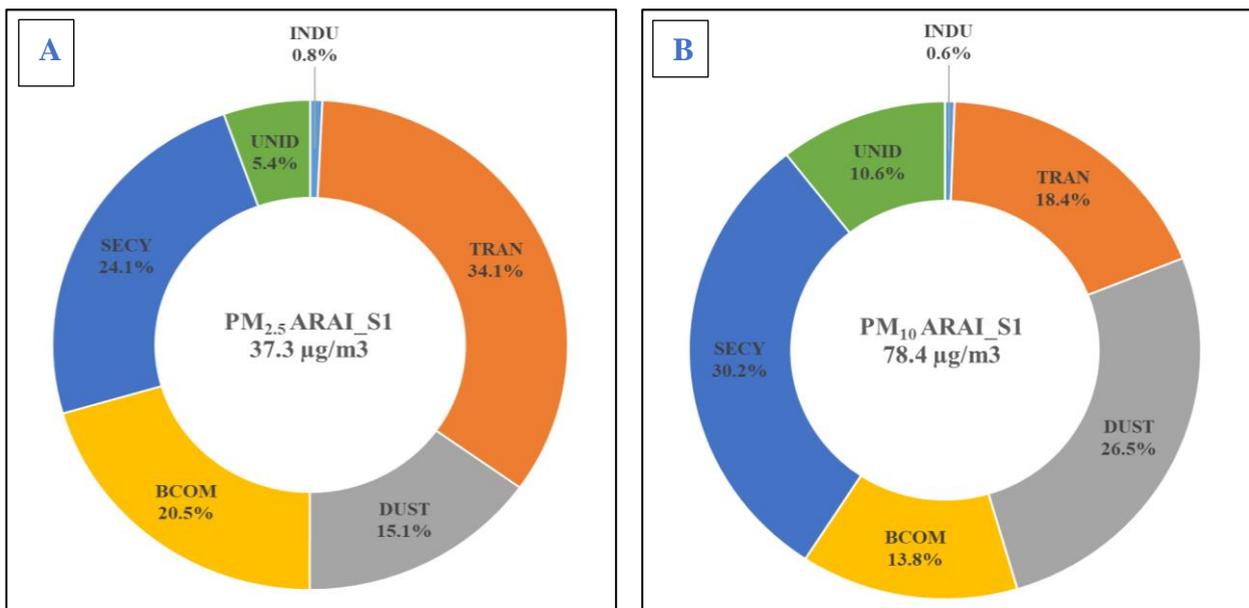


Figure 52 Sectoral source contributions to PM<sub>2.5</sub> (A) and PM<sub>10</sub> (B) at S1 i.e. Gokhibaba Ashram during the summer season in Bhubaneswar region

### 2.9.2.2. Site 2: OSPCB Head Office

Fig. 53 shows the sectoral source contributions to PM<sub>2.5</sub> and PM<sub>10</sub> at S2 i.e. OSPCB Head Office during summer season. The summer season mean modelled PM<sub>2.5</sub> and PM<sub>10</sub> concentrations at this site were 48.5 µg/m<sup>3</sup> and 84.6 µg/m<sup>3</sup>, respectively. The summer time PM<sub>2.5</sub> mass was found to be dominated by transport sources with highest contribution of 34.8%. The other sources of PM<sub>2.5</sub> at this site were identified as dust (19.1%), secondary aerosols (18.6%), biomass and solid waste combustion (18.0%), and industry (0.8%). The summer-time PM<sub>10</sub> concentrations at this site was dominated by dust (33.1%), followed by transport (22.2%), secondary aerosols (22.0%), biomass and solid waste combustion (14.0%), and industry (0.8%). About 8.6% and 7.1% in PM<sub>2.5</sub> and PM<sub>10</sub> mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

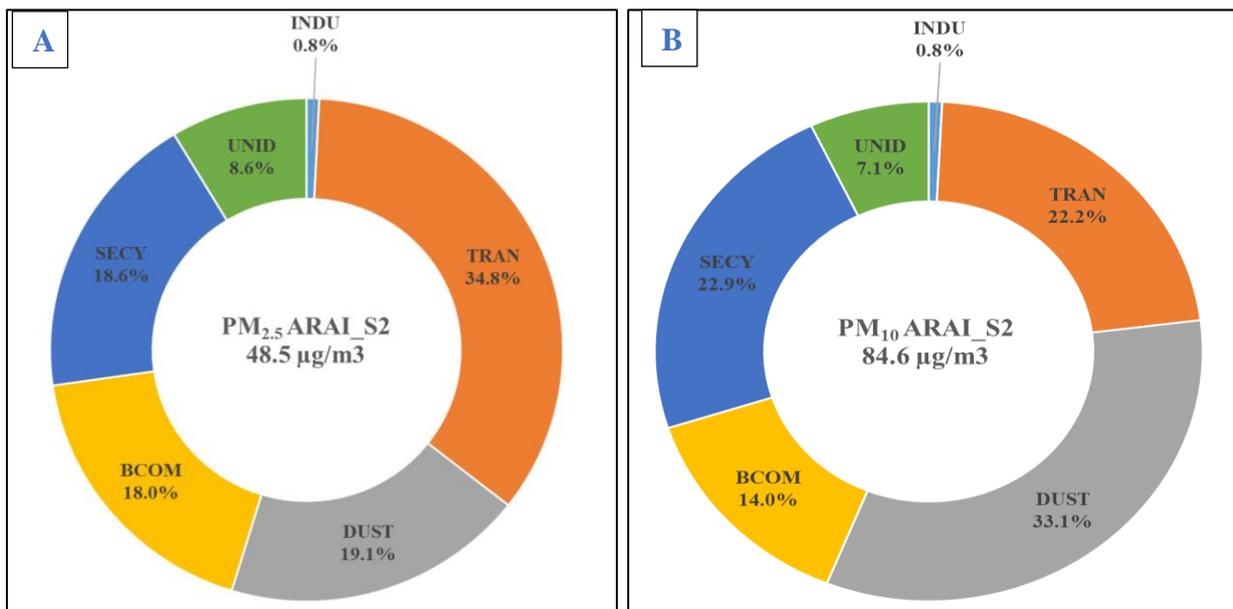


Figure 53 Sectoral source contributions to PM<sub>2.5</sub> (A) and PM<sub>10</sub> (B) at S2 i.e. OSPCB Head Office during summer season

### 2.9.2.3. Site 3: Office of Chief Instructress Home Economic Training Centre

Fig. 54 shows the sectoral source contributions to PM<sub>2.5</sub> and PM<sub>10</sub> at S3 i.e. Office of Chief Instructress Home Economic Training Centre during summer season. The summer season mean modelled PM<sub>2.5</sub> and PM<sub>10</sub> concentrations at this site were 39.9 µg/m<sup>3</sup> and 117.5 µg/m<sup>3</sup>, respectively. The summer time PM<sub>2.5</sub> mass was found to be dominated by transport sources with highest contribution of 37.8%. The other sources of PM<sub>2.5</sub> at this site were identified as biomass and solid waste combustion (27.5%), dust (18.2%), secondary aerosols (12.0%) and industry (0.9%). The summer-time PM<sub>10</sub> concentrations at this site was dominated by dust (33.7%), followed by transport (21.3%), biomass and solid waste combustion (19.7%), secondary aerosols (15.8%) and industry (0.7%). About 3.6% and 8.8% in PM<sub>2.5</sub> and PM<sub>10</sub> mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

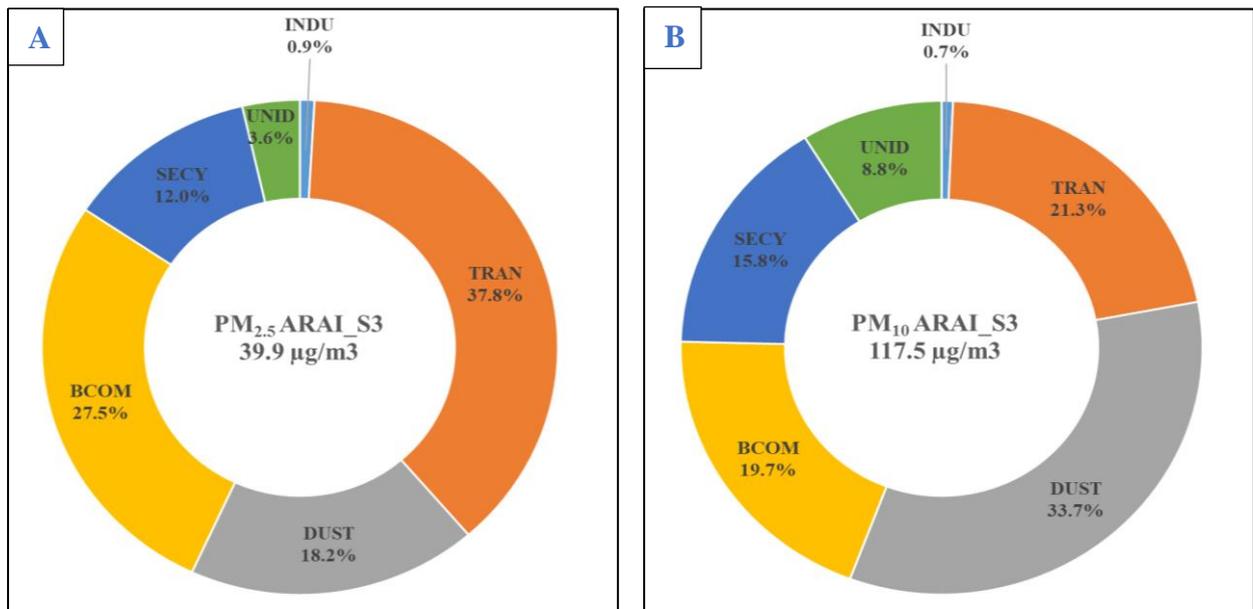


Figure 54 Sectoral source contributions to PM<sub>2.5</sub> (A) and PM<sub>10</sub> (B) at S3 i.e. Office of Chief Instructress Home Economic Training Centre during summer season

#### 2.9.2.4. Site 4: RO Office, SPCB

Fig. 55 shows the sectoral source contributions to PM<sub>2.5</sub> and PM<sub>10</sub> at S4 i.e. RO Office, SPCB site during summer season. The summer season mean modelled PM<sub>2.5</sub> and PM<sub>10</sub> concentrations at this site were 47.0 µg/m<sup>3</sup> and 92.5 µg/m<sup>3</sup>, respectively. The summer time PM<sub>2.5</sub> mass was found to be dominated by biomass and solid waste combustion sources with highest contribution of 37.7%. The other sources of PM<sub>2.5</sub> at this site were identified as transport (25.5%), secondary aerosols (15.1%), dust (11.7%), and industry (1.1%). The summer-time PM<sub>10</sub> concentrations at this site were also dominated by biomass and solid waste combustion (28.6%), followed by dust (22.6%), secondary aerosols (20.8%), transport (15.1%), industry (0.8%). About 8.9% and 12.1% in PM<sub>2.5</sub> and PM<sub>10</sub> mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

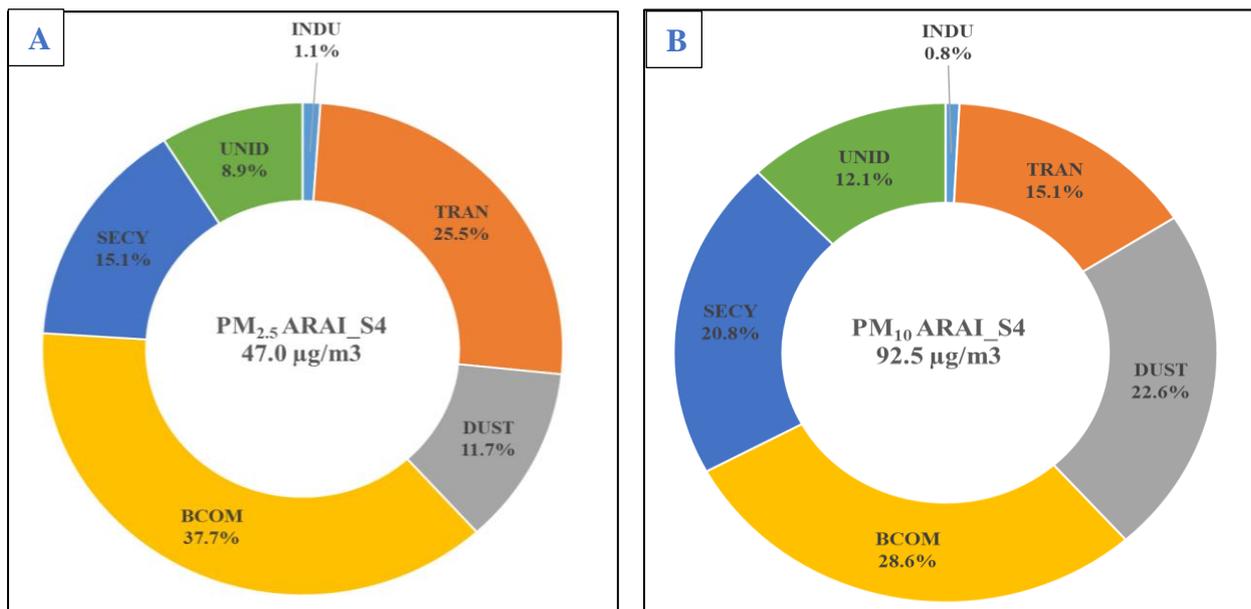
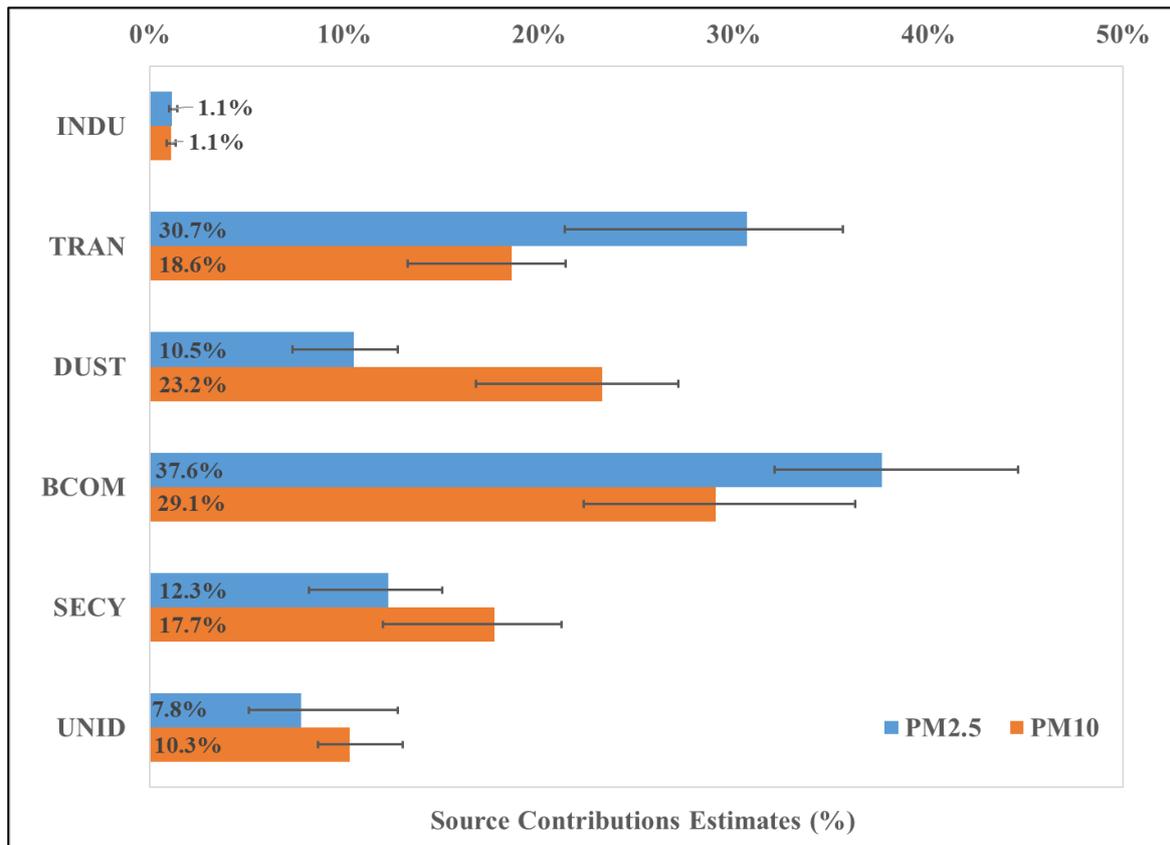


Figure 55 Sectoral source contributions to PM<sub>2.5</sub> (A) and PM<sub>10</sub> (B) at S4 i.e. RO Office, SPCB during summer season

### 2.9.3. City-level source contribution analysis

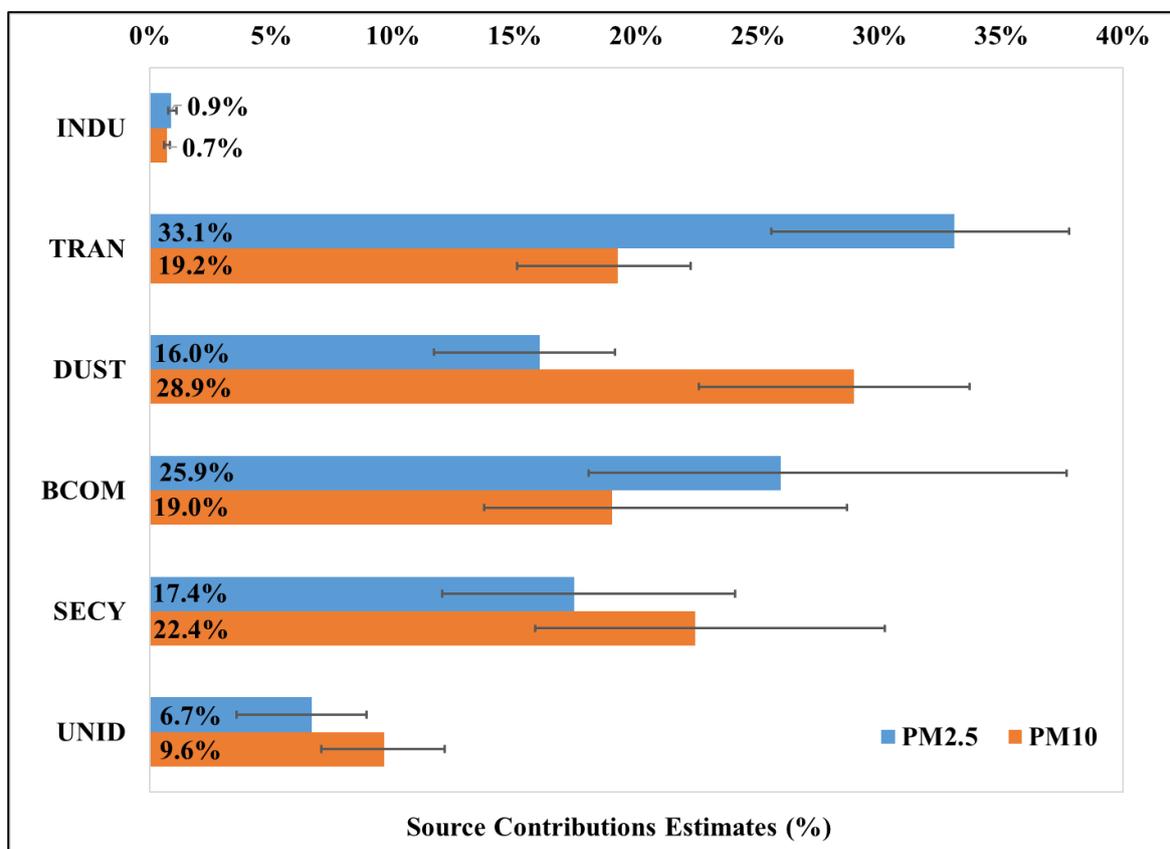
The city-level average source contributions were determined, using the site-wise source contribution estimates obtained in the previous section. Fig. 56 and 57 presents the average source contributions to ambient PM<sub>2.5</sub> and PM<sub>10</sub> at Bhubaneswar during winter and summer seasons, respectively.

Overall, the winter-time PM<sub>2.5</sub> mass at Bhubaneswar (Fig. 56) are found to be dominated by solid waste and biomass combustion sector with highest contribution of 37.6%. The other sources of PM<sub>2.5</sub> at Bhubaneswar are identified as transport (30.7%), secondary aerosols (12.3%), dust (10.5%), and industry (1.1%). Similarly, the winter-time PM<sub>10</sub> mass at Bhubaneswar is found to be dominated by solid waste and biomass combustion (29.1%), followed by dust (23.2%), secondary aerosols (17.7%), transport (18.6%), and industry (1.1%). Additionally, about 7.8% and 10.3% mass of PM<sub>2.5</sub> and PM<sub>10</sub> remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.



*Figure 56 City-level source contribution estimates (SCE) for Bhubaneswar region using CMB receptor model during winter season (December 12 – 27, 2022)*

The summer-time PM<sub>2.5</sub> mass at Bhubaneswar (Fig. 57) is found to be dominated by transport with highest contribution of 33.1%. The other summer-time sources of PM<sub>2.5</sub> at Bhubaneswar region are identified as solid waste and biomass combustion (27.4%), secondary aerosols (17.4%), dust (16.0%) and industry (0.9%). Similarly, the summer-time PM<sub>10</sub> mass at Bhubaneswar is also found to be dominated by dust (28.9%), followed by secondary aerosols (22.4%), transport (19.2%), solid waste and biomass combustion (19.0%), and industry (0.7%). Additionally, about 6.8% and 10.5% mass of PM<sub>2.5</sub> and PM<sub>10</sub> remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.



*Figure 57 City-level source contribution estimates (SCE) for Bhubaneswar region using CMB receptor model during summer season (April 11 – 29, 2023)*

(Note: The horizontal blue and orange coloured bars in Fig 56 and 57 represent the mean SCE percentage in PM<sub>2.5</sub> and PM<sub>10</sub>, respectively while the error bars represent the range of estimated SCE among four sampling sites.)

## **Chapter 3: Emission Inventory**

### **3.1. Introduction**

An emission inventory (EI) is a comprehensive listing by source of air pollutant in a geographic area during a specific time period. Emission inventories are one of the fundamental components of Air Quality Management Plans to measure progress/changes over time to achieve cleaner air and to determine compliance with environmental regulations (Shrestha et al., 2013).

Air pollutant emission inventory is a crucial input for pollutant emission control and air quality management (Xu et al., 2020). Further, emission inventories are an essential input to mathematical models that estimate air quality (EPA, 2022). Emission inventory and dispersion models, together provide guidance for decision-makers by supplying information on pollutant emission sources and their characteristics. Emission inventories and air quality modelling are two significant components of air quality management in urban areas.

### **3.2. Objectives and Scope of Work**

The main objective of this study is development of baseline emission inventory (Year: 2022) of air pollutant loads originating from eleven sectors in Bhubaneswar region. The scope of this study includes:

- Quantification of emission loads originating from sectors including: Transport, Re-suspended road dust, Residential, Open waste burning, Hotels, Restaurants and Bakeries, Construction, Diesel generators, wind-blown riverbed erosion dust, Industries, Brick kilns, Crematoria and Aviation in Bhubaneswar region.
- Air pollutants considered in this research includes: particulate matter having aerodynamic diameter less than or equal to 10 microns (PM<sub>10</sub>), particulate matter having aerodynamic diameter less than or equal to 2.5 microns (PM<sub>2.5</sub>), sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs).
- The spatial resolution of emission inventory is: 2 x 2 km<sup>2</sup> over the study area
- The temporal resolution of emission inventory is monthly.

### 3.3. Approach to Emission Inventory Development

Figure 58 shows the methodology adopted in development of emission inventory for Bhubaneswar region. The first phase of the emission inventory development involves research on previous emission inventories in the region, reconnaissance surveys, collection of secondary datasets. Based on this data analysis, air pollution sources in the study domain were identified. Once the air polluting sources in the study domain are identified, the primary data collection surveys were taken up for different sectors.

There are several estimation methods to calculate emissions. This study uses the most widely used approach based on emission factor and activity rate. A literature review was carried out for selection of emission factors. Emission factors for vehicular sector were adopted from Automotive Research Association of India (ARAI, 2010, 2018), while for other sectors India specific and local emission factors have been used as far as possible.

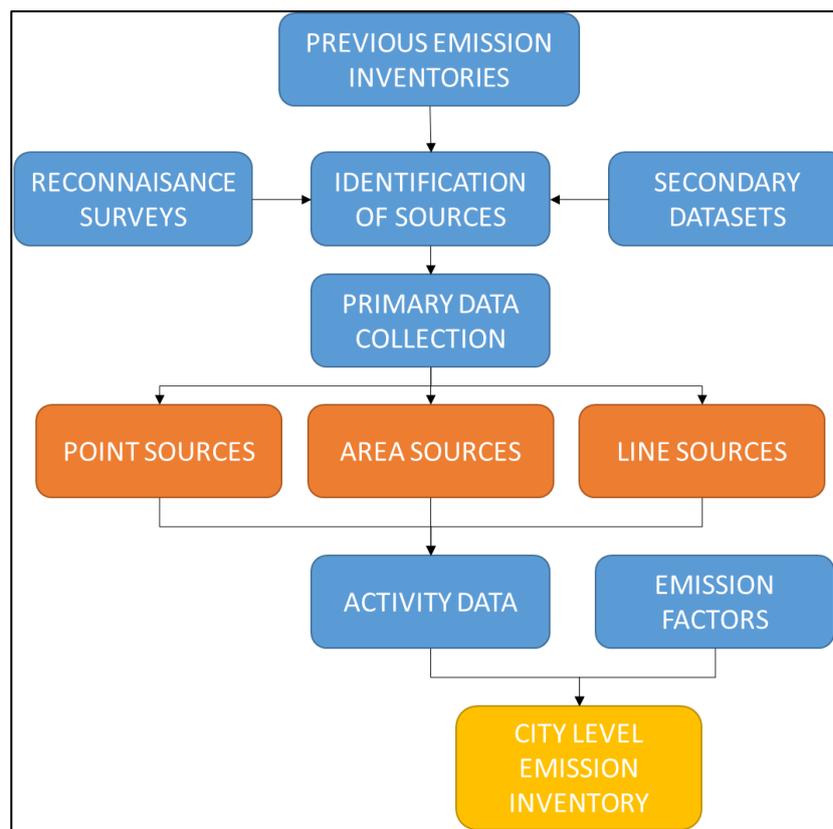


Figure 58: Approach adopted for emission inventory development at regional level

The study area was divided into high resolution grid cells at 2 X 2 km<sup>2</sup> grids using GIS tools. A total 120 grid cells were formed. Emission inventory has been prepared for the study area and thereafter allocated to high resolution grid cells. Fig. 59 presents the gridded study domain (2 x 2 km<sup>2</sup>). The methodologies followed for estimation of emissions from different sectors are described in subsequent sections.

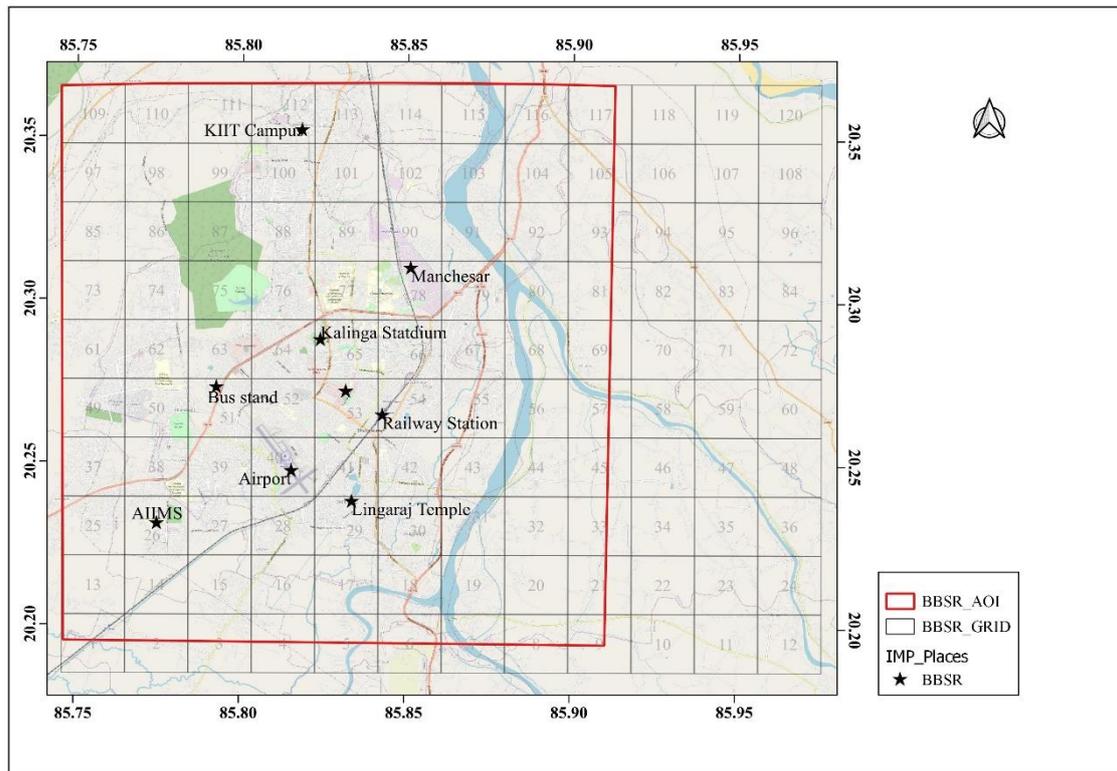


Figure 59: Map showing study area overlaid with emission inventory grids with horizontal spacing of 2 x 2 km<sup>2</sup>

### 3.4. Methodology

The methodology follows a bottom-up estimation of emissions using activity rates for each sector and the measured emission factors (EFs) in India wherever possible. The bottom-up approach uses source-specific and category-specific data at the most refined spatial level to estimate emissions. The emissions estimated for individual sources are summed up to obtain a region-level inventory. The sector-specific activity rate is uniquely estimated across each sub-sector using available primary and secondary data such as fuel consumption, daily vehicle kilometres travelled, registered number of vehicles, and production capacities. The approach also incorporates latest process technologies and control measures for particulates and other species in Industrial and vehicular sectors.

The widely used emission estimation method based on activity rate and emission factor is used. This method estimates the rate at which a pollutant is released to the atmosphere as a result of certain processes (Shrestha et al., 2013). Table 4 shows the different air pollution sources inventorised for study domain. Emission calculation can be expressed by using the following equation (6):

$$E = A \times EF \times \frac{(100 - CE)}{100} \dots \dots \dots (6)$$

where,

E = Emission load

A = Activity rate

EF = Emission factor

CE = Overall control efficiency (%).

*Table 4: Different air pollution sources inventorised in this study for Bhubaneswar region*

Source Type	Sources Included
Point Sources	Industries, Crematoria, Brick kilns
Area Sources	Residential, Open waste burning, Hotels, restaurants and bakeries, Construction, Diesel generators, Riverbed erosion
Line Sources	Transport, Re-suspended road dust

Details of primary and secondary data collection surveys are provided in sectoral manner in subsequent sections. Air pollution sources were categorized into three main types i.e. point, area and line sources and details of sectors included in each type are provided in Table 4. Area sources are sources of pollution that emit a substance from a specific area. These include small pollution sources such as residential, hotels, restaurants and bakeries, construction sites, etc. Although emissions from individual area sources are relatively small per unit, collectively their emissions can be of concern, particularly where large numbers of sources

are located in heavily populated areas. Line sources mainly include both on-road vehicles such as two wheelers, cars, trucks and buses (Shrestha et al., 2013).

### 3.4.1. Primary and secondary data collection

The data collection is a pre-requisite for development of the regional emission inventory. Two types of data collection approaches are used in this study i.e. primary and secondary data collection. The first approach i.e. primary data collection involves field surveys at identified locations for residential, commercial, and industrial fuel consumption, parking lot surveys to understand details of vehicle fleet, classified vehicle surveys to understand traffic count for various vehicle types. The second approach i.e. secondary data collection involves extracting relevant data from published reports, research papers, and government department website. Table 5 and 6 summarizes the primary and secondary data collection used in this study.

*Table 5: Summary of primary data collection surveys carried out in this study*

Sr. No.	Sector	Primary Data Collection Surveys
1.	Transport	<ul style="list-style-type: none"> <li>• Classified vehicle counts</li> <li>• Parking lot / Fuel station surveys</li> </ul>
2.	Re-suspended road dust	<ul style="list-style-type: none"> <li>• On -road dust sampling to determine the silt loading rates</li> </ul>
3.	Residential	<ul style="list-style-type: none"> <li>• Fuel consumption surveys</li> </ul>
4.	Hotels, Restaurants. Bakeries and Open eateries	<ul style="list-style-type: none"> <li>• Fuel consumption surveys</li> </ul>
5	Diesel Generators	<ul style="list-style-type: none"> <li>• Fuel consumption surveys</li> </ul>

**Table 6 Summary of secondary data sources used in this study**

Sr. No.	Sector	Secondary Data Sources
1.	Transport	<ul style="list-style-type: none"> <li>• VAHAN database</li> <li>• MoRTH Annual Reports</li> <li>• Road network from Openstreetmap and Google Inc.</li> </ul>
2.	Construction	<ul style="list-style-type: none"> <li>• Google Earth Inc.</li> </ul>
3.	Hotels, Restaurants, Bakeries and Open eateries	<ul style="list-style-type: none"> <li>• Numbers, types, and locations of facilities through online food delivery portals</li> </ul>
4.	Open waste burning	<ul style="list-style-type: none"> <li>• Solid waste generation, processing and disposal statistics</li> </ul>
5.	DG Sets	<ul style="list-style-type: none"> <li>• Numbers, types, and locations of facilities through open street map, wherever applicable.</li> </ul>
6.	Brick Kilns	<ul style="list-style-type: none"> <li>• Google Earth Inc.</li> </ul>
7.	Industry	<ul style="list-style-type: none"> <li>• OSPCB database</li> </ul>
8.	Residential	<ul style="list-style-type: none"> <li>• National Family Health Survey (NFHS) 2019-2021</li> </ul>
9.	Riverbed erosion	<ul style="list-style-type: none"> <li>• Google Earth Inc.</li> </ul>

### 3.4.2. Transport

The transport sector emissions are calculated using data generated from primary surveys for on-road vehicle counts, parking lot surveys, and data available in public domain from different government departments at state and local level. The vehicular exhaust emissions are calculated using equation (7):

$$\text{Transport Emissions} = \text{VKT} \times \text{EF}_{EX} \dots \dots \dots (7)$$

Where, EF<sub>EX</sub> is the emission factor (g/km) for a particular category of vehicle of particular vintage, fuel and engine technology and VKT is Vehicle Kilometers Travelled, by same category of vehicle, in a day. As illustrated in Eq. 1, the emission factor (EF) is an important input required for quantifying the vehicular emissions at city level. The vehicular

emissions factors developed by Automotive Research Association of India (ARAI) for in-use Indian vehicles (ARAI, 2010; 2018) are used in this study.

#### **3.4.2.1. Road network digitization**

Road network in the study area was digitized using Google Earth application (Fig. 60). Roads in Bhubaneswar region are classified into five categories viz. i) highways, ii) major roads, iii) intermediate roads, iv) minor roads and v) residential roads. After complete digitization, road lengths were calculated for each link in the network using GIS software. Category-wise gridded road lengths were also computed using GIS software.

#### **3.4.2.2. Reconnaissance survey**

A Reconnaissance survey was conducted in the Bhubaneswar region to select the locations for traffic count and parking lot surveys. Reconnaissance surveys helped in understanding the traffic movement in the city, major traffic locations, type of vehicles, etc. Total 13 survey locations were identified in the Bhubaneswar region to perform the classified vehicle count surveys and 4 areas/localities around the sampling sites were selected for Parking lot surveys.

#### **3.4.2.3. Traffic counts and vehicle fleet characteristics**

Estimation of reasonably accurate vehicular emissions requires a good characterisation of the in-service vehicle fleet. Important characteristics of vehicle fleet include information on vehicle type, size, fuel type, age and emission control technologies. The historic vehicle registration data provides preliminary information vehicle type, size and fuel-type. The vehicle fleet in Bhubaneswar region was categorised into six categories: 2-wheelers (motorcycles, scooters and mopeds), autos, passenger cars both private and commercial, light commercial vehicles (LCV) such as delivery vans, heavy duty vehicles (HDV) such as trucks and lorries and buses and coaches. Fig. 61 depicts the vehicle categories used in this study.

Traffic count surveys were carried out to obtain the information of on-road vehicles plying in the city, such as total number of vehicles, variation of vehicles on different road categories (major, minor and arterial), transit vehicles, temporal variations, etc. Traffic count surveys were conducted by manual counting by teams of surveyors. At each of the selected location, category-wise traffic count data is collected in single direction. The vehicles are

counted during the peak hours i.e. 08:00 to 13:00 hours and 15:00 to 18:00 hours on selected weekdays and weekend during November, 2022 to January, 2023. Parking lot surveys were also carried out to understand the distribution of existing vehicular fleet as per model, vintage, technology, fuel mix, average daily distance travelled, occupancy, and mileage. Parking lot surveys are carried out in 4 areas/localities around the selected sampling sites (S1-S4) in Bhubaneswar region during November, 2022 to January, 2023. Table 7 and 8 shows the details of locations of vehicle count surveys and parking lot surveys respectively.

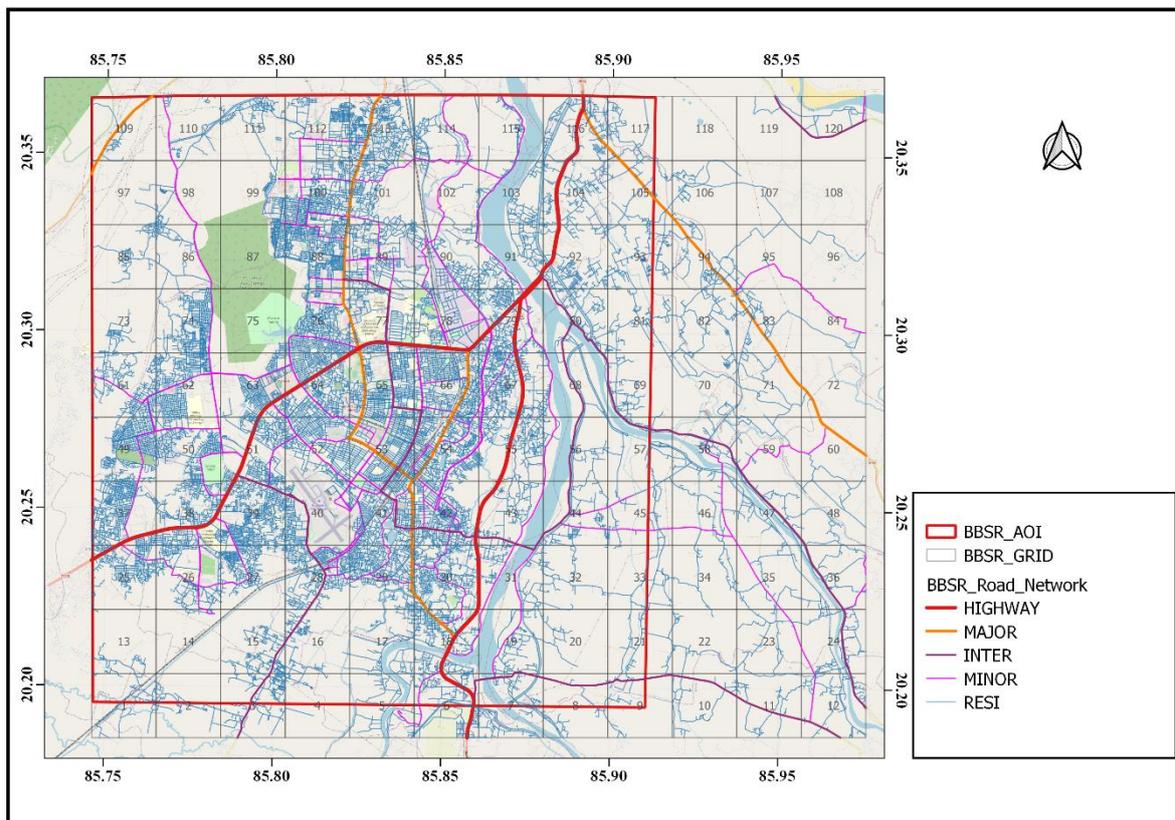


Figure 60: Map showing road network in Bhubaneswar region and surrounding areas digitized using OpenStreetMap and Google Earth Applications

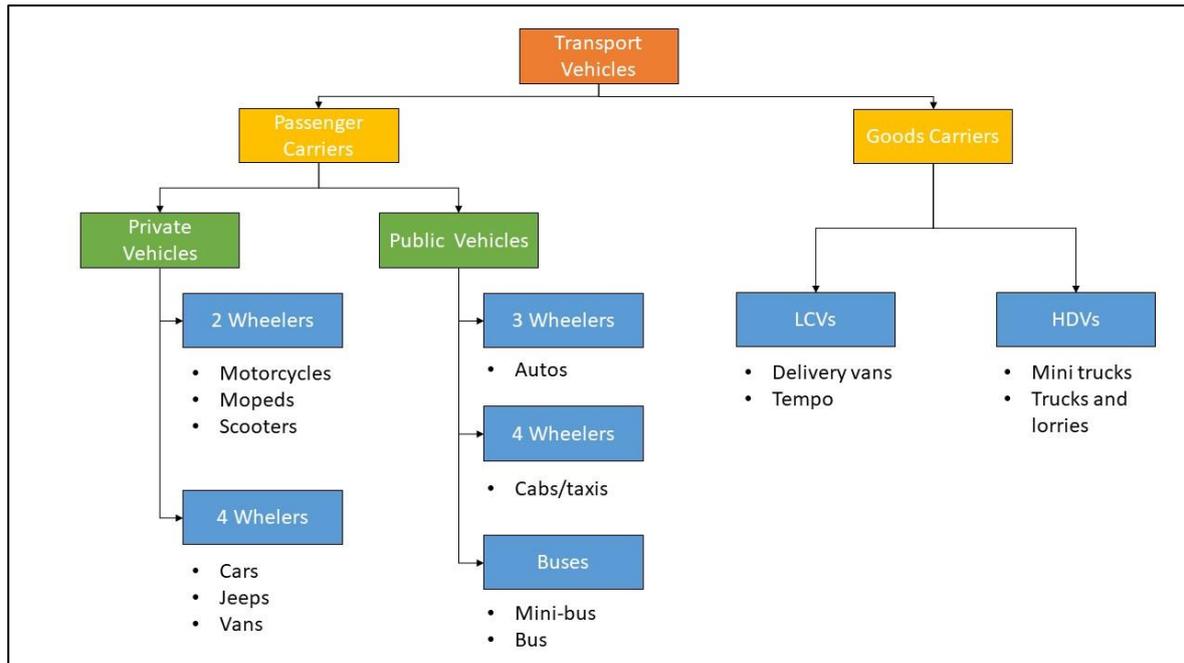


Figure 61: Vehicle categories used in this study

Each vehicle category is further differentiated in up to four fuel or engine types respectively: Gasoline, Diesel, Natural Gas, and electric vehicles. In addition, vehicular emission calculations require the vehicle fleet by age, as mass emission factors are significantly different for each vehicle type and control technology. Based on approach adopted by Baidya and Borken-Kleefeld (2009), the in-service vehicles were calculated using Survival function which models the vehicle's finite service life. The survival rate, which is a fraction of vehicles survived in the fleet after a certain age, was calculated for each vehicle category considered in Bhubaneswar region. The data generated through road network mapping, vehicle count surveys, parking lot surveys, and vehicle registration analysis was used to calculate the vehicle kilometres travelled (VKT) by different vehicle types on each road type.

Emission factors (EF) are essential input required to calculate the emissions originating from transport sector. Emissions measured on vehicle using chassis dynamometers are expressed in grams of pollutant per unit of distance travelled (g/km). Vehicular emissions are dependent on the large range of variables such as vehicle technology, age, condition, road profiles, driving habits, emission control regulatory levels, fuel and payload (Bawase et al., 2021). For this study, EFs developed by ARAI during 2010 and 2018 are used to calculate the total on-road vehicular emissions. It is important to note that, as BS-VI vehicles were recently introduced in i.e. year 2020, the mass emission factors for in-service vehicles in India are not

available. Hence, the emission factors for such vehicles were derived using BS-VI emission limits.

*Table 7: Locations of vehicle count surveys in Bhubaneswar region*

Code	Road Type	Road Name	Latitude	Longitude
VC1	C.P.D.O Office, Chennai Kolkata Highway	Highway	20.28693	85.81095
VC2	Bidyut Marg	Major	20.28382	85.82686
VC3	CRP-DAV Road, Nayapalli	Intermediate	20.28005	85.81237
VC4	Jharpada Flyover, Laxmi Sagar, Puri-Cuttack Road	Major	20.2764	85.85257
VC5	Jharpada Road	Minor Road	20.27492	85.86385
VC6	Jharpada, Jail Road	Intermediate	20.27773	85.86002
VC7	Nandankanan Road	Major	20.34461	85.82352
VC8	KIIT Road/ Shikhar Chandi Road	Intermediate	20.35351	85.82301
VC9	IT Park Road	Minor	20.36037	85.81596
VC10	Jatni Road	Major	20.22798	85.81445
VC11	Lingaraj Temple Road	Intermediate	20.23374	85.83205
VC12	Mahatab Road	Minor	20.23501	85.82888
VC13	Janpath Road	Major	20.27951	85.84373

*Table 8 Locations of Parking Lot Surveys in Bhubaneswar region*

Location No.	Area Name
P1	Gokhibaba Ashram Area
P2	Nayapalli area
P3	Jharapada area
P4	Patia area

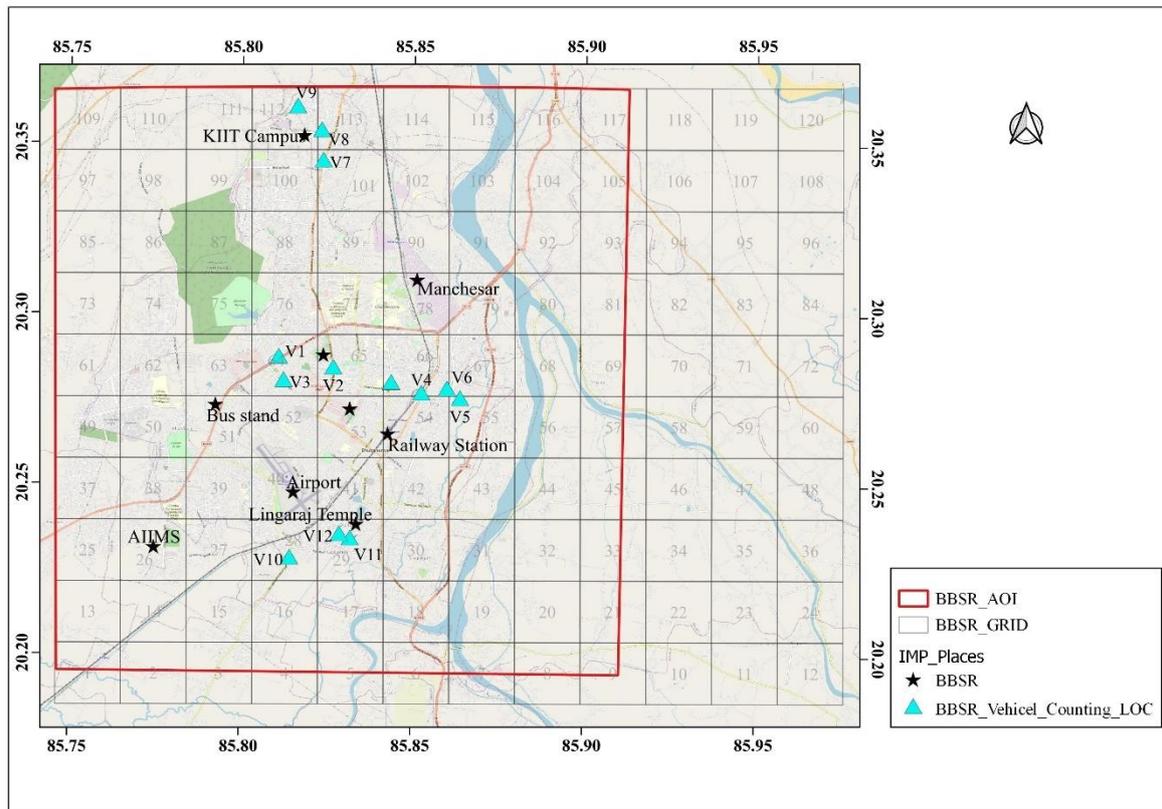


Figure 62: Map showing selected locations in Bhubaneswar region for vehicle counting surveys.

Fig. 63 presents the classified vehicle count observed at different types of roads in region. Highways and major roads such as VC1, VC7 and VC4 exhibited highest vehicular population in a day, followed by intermediate roads and minor roads. Further, it is interesting to note that the observed vehicle population remains more or less similar, on both weekdays and weekend except VC1, VC4, VC7 and VC13 locations, which exhibited a significant contrast in vehicular population. This can be attributed to regular traffic during office hours on weekdays.

Fig. 64 depicts the observed percentage distribution of vehicles according to Bharat standards in Bhubaneswar region. A total of 860 vehicles were surveyed in the region during the primary surveys. The BS-III category vehicles are observed to be maximum (46%) followed by BS-IV (31%), BS-VI (17%), BS-II (5%), and BS-I (1%).

Fig. 65 shows the estimated daily vehicle kilometres travelled by each category of vehicles in the Bhubaneswar region. The daily VKT is estimated to be 363.8 lakh km and is

dominated by two wheelers (72%) followed by passenger cars (13.8%), autos (7.8%). All other vehicle categories together constitute about 6% of the daily VKT in Bhubaneswar region.

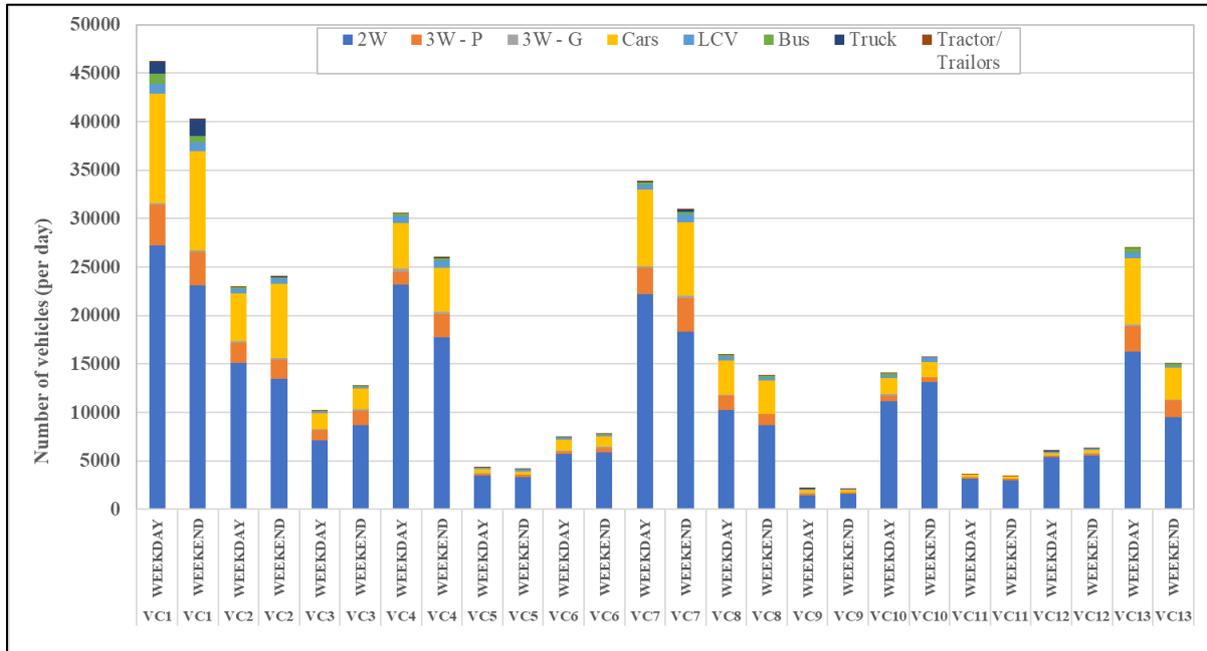


Figure 63: Classified vehicle counts observed at selected locations in Bhubaneswar region during the primary surveys.

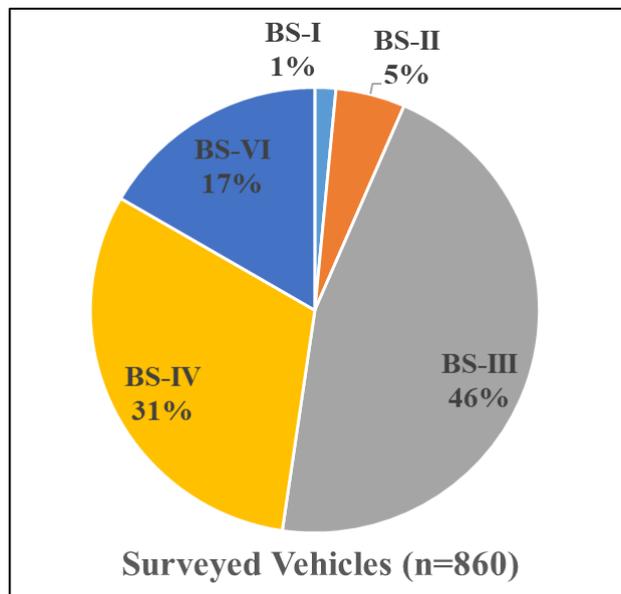
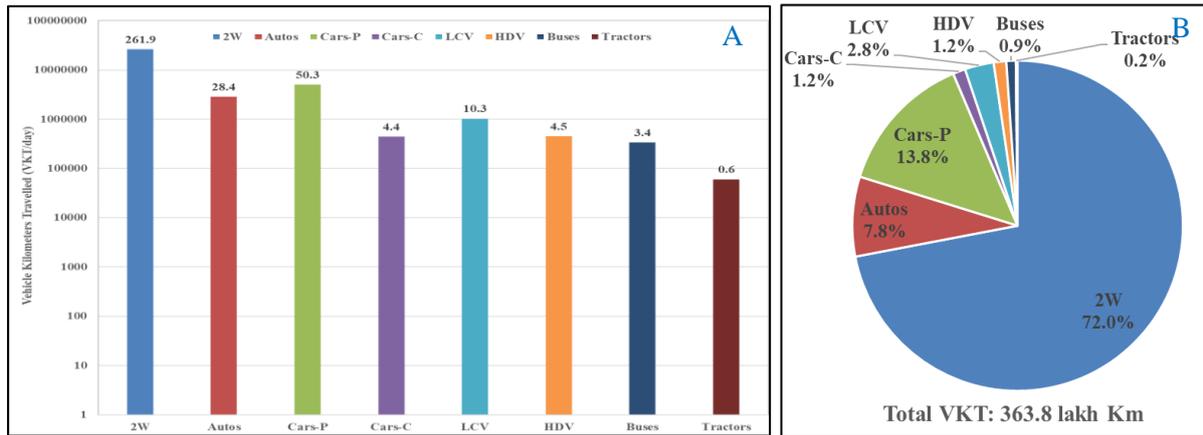


Figure 64: Distribution of vehicles as per different Baharat standards (BS) in Bhubaneswar region obtained through parking lot surveys.



**Figure 65: Daily vehicle kilometres travelled (A) and percent distribution (B) by different category of vehicles in Bhubaneswar region.**

In 65 (A), the numbers of top of each bar represent daily VKT in lakh and y-axis scale is expressed as a logarithmic scale.

### 3.4.3. Road Dust Resuspension

Emissions from paved road dust re-suspension due to movement of vehicles were calculated using US EPA (AP-42) method. These dust emissions due to movement of vehicles varies with the silt loading on the road surface and also the average weight of the vehicles plying on the road. The term silt loading (sL) refers to the mass of the silt-size material (equal to or less than 75 µm in physical diameter) per unit area of the road surface. Silt loading values are calculated based road dust sample collection at previously listed vehicle counting locations. Particulate matter emissions from re-suspension of road dust due to movement of vehicles on paved roads were calculated using Eq. 8:

$$\text{Emissions load} = \text{VKT} \times \text{EF}_{RD} \dots \dots \dots (8)$$

where, VKT is Vehicle Kilometer Travelled (km/day) and EF is paved road dust emission factor and calculated using Eq. 9:

$$\text{EF}_{RD} = k \times w^{1.02} \times (\text{sL})^{0.91} \times \left(1 - \frac{P}{4N}\right) \dots \dots \dots (9)$$

Where,

EF = particulate emission factor (having units matching the units of k)

k = constant (function of particle size) in g/VKT, value of k for PM<sub>10</sub> and PM<sub>2.5</sub> is 0.62 and 0.15, respectively.

sL = road surface silt loading in g/m<sup>2</sup>

w = average weight of the vehicles (in tons) travelling on the road

P = number of “wet” days with at least 0.254 mm (0.01 in) of precipitation during the averaging period,

N = number of days in the averaging period (e.g., 365 for annual).

The road dust samples were collected from selected locations to determine the silt loading rates for different category of roads in Bhubaneswar region. The gross vehicle weights for different classes are obtained from vehicle specifications sheets through online surveys. Number of rainy and wet days in year 2022, were obtained from ERA5 reanalysis data used for dispersion modelling. The paved road emission factors for PM<sub>2.5</sub> and PM<sub>10</sub> are listed in Table 9. These emission factors are then multiplied by gridded VKT values obtained earlier for calculation of vehicular emissions to obtain total road dust emissions.

*Table 9: Road dust re-suspension emission factors (in g/km) used in this study*

Fractio n	AREA TYPE	HIGHWAY	MAJOR	INTERME DIATE	MINOR	RESI
PM <sub>2.5</sub>	City	0.33	0.13	0.04	0.17	0.14
PM <sub>2.5</sub>	Peri-urban	0.33	0.68	0.48	0.26	0.22
PM <sub>2.5</sub>	Industrial	0.33	0.41	0.18	0.57	0.47
PM <sub>2.5</sub>	Rural	0.33	0.67	0.51	0.17	0.22
PM <sub>10</sub>	City	1.37	0.52	0.16	0.69	0.57
PM <sub>10</sub>	Peri-urban	1.37	2.82	1.97	1.09	0.92
PM <sub>10</sub>	Industrial	1.37	1.68	0.76	2.36	1.95
PM <sub>10</sub>	Rural	1.37	2.76	2.10	0.71	0.92

### 3.4.4. Residential

The basic equation (10) employed for emission estimation from the residential sector is:

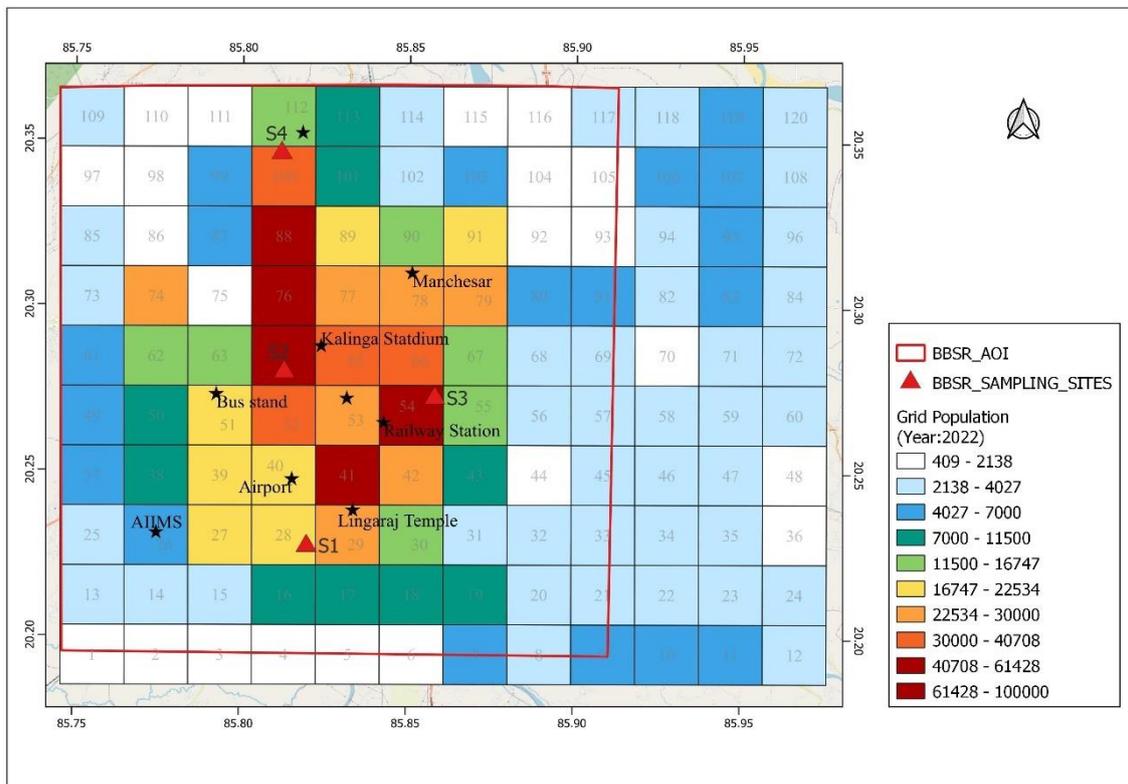
$$E_p = \sum_{f=1}^6 \text{Pop}_f \times C_f \times \text{EF}_{f,p} \dots \dots \dots (10)$$

where, E<sub>p</sub> is the emissions of a particular pollutant (p) from the residential sector, Pop<sub>f</sub> is the population of the study region using a particular fuel (f), C<sub>f</sub> is the per capita consumption of a particular fuel (f), and EF<sub>f,p</sub> is the Emission factor in (g/kg) of the particular pollutant (p) of the particular fuel type (f). Six major fuels are used in the residential households for cooking

and lighting purposes– a) Fuel wood, b) dung cake, c) crop residue, d) coal, e) kerosene and f) LPG and were included in the estimation of emissions.

The latest census data for Bhubaneswar region is available for year 2011 but the region has undergone huge transformation in the last decade and old data cannot be used. Hence, the gridded population of the study area (Refer Fig. 66) was estimated using suitable population projection techniques and assumptions.

The percentage of population using different fuels and daily average fuel consumption is derived from the primary surveys conducted in Bhubaneswar region as a part of this study. The emission factors for residential sector used in this study are summarized in Table 10.



*Figure 66 Map showing the estimated gridded population of the study area in year 2022*

**Table 10: Emission factors (g/kg) of different pollutants from different fuel types used in the residential sector**

Fuel type	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>x</sub>	CO	NMVOC
Fuel wood	6.8	4.6	0.8	1.7	66.5	15.9
Crop residue	8.6	5.7	0.7	1.8	64	8.5
Dung cake	10.5	4.4	0.6	1	78.6	24.1
Coal	8.3	4	15.3	2.16	59.5	10.5
Kerosene	3.6	3	0.4	1.3	43	17
LPG	0.4	0.4	0.4	2.9	2	19

#EFs adopted from Datta and Sharma (2014)

### 3.4.5. Open Waste Burning

The basic equation (11) followed to estimate the emissions of different pollutants from the open burning of solid waste is:

$$E_p = W_b \times EF_p \dots \dots \dots (11)$$

Where,  $E_p$  the emission of a particular pollutant from the burning of the refuse material,  $W_b$  is the quantity of waste materials burnt in an area, and  $EF_p$  is the emission factor of the particular pollutant (p) from the burning of the waste material.

In this study, the MSW burnt for the sake of disposal at the household level or on the street ( $W_b$ ) is quantified using methodology adopted by Sharma et al. (2019). The MSW generated in the study domain is calculated using per capita MSW generation rate of ~360 gm. MSW burnt refers to the non-inert fraction of the uncollected MSW left behind after collection ( $MSW_C$ ), recycling ( $MSW_R$ ), and secondary use as fodder, fertilizer, and fuel ( $MSW_F$ ).  $f_i$  in eq. 12 stands for the inert fraction of the waste (ash and dust), which is estimated to be about 11.73% for similar regions. Additionally, it is assumed that out of the uncollected waste, 60% of the total waste available to be burned that is actually burned. (IPCC, 2006; Wiedinmyer, 2014).

$$W_b = (MSW_P - MSW_C - MSW_R - MSW_F) \times (1 - f_i) \times 0.6 \dots \dots \dots (12)$$

The waste burnt daily is dependent upon the population, per capita waste generation, waste collection efficiency and fraction of uncollected waste burnt. The details on waste generation and waste collection are obtained from statistics available in public domain. The emission factors of various pollutants considered in present study are illustrated in Table 11.

**Table 11: Emission factors (g/kg) for open waste burning**

Pollutants	EF (g/kg)	References
PM <sub>10</sub>	14	Sharma et al., 2019
PM <sub>2.5</sub>	13	
SO <sub>2</sub>	0.892	
NO <sub>x</sub>	2	
CO	67	
NMVOCs	14.5	TERI, 2016

### 3.4.6. Hotels, Restaurants and Bakeries

Emissions from this sector are mainly generated due to coal and wood used for cooking activities in hotels, restaurants, bakeries and open eateries. Additionally, coal and wood are also used in tandoors and/or barbeques. The common fuels used by restaurants/hotels in Bhubaneswar region are LPG, coal and wood. The equation (12) used for calculating emissions by this sector:

$$E_p = C_f \times EF_{f,p} \dots \dots \dots (12)$$

Where, E<sub>p</sub> is the emission of a particular pollutant (p), C<sub>f</sub> is the Fuel consumption by the hotel/ restaurant and EF is Emission factor for the pollutant (p) generated by the use of fuel (f).

Primary surveys were conducted in different localities of Bhubaneswar region to understand the fuel usage pattern in hotels, restaurants, bakeries ad open eateries. The locations of hotels, restaurants, bakeries are obtained from online food delivery portals and google maps. The data collected fuel consumption in restaurants and open eateries is used to quantify the emissions for year 2022. The emissions factors are used from the CPCB (2011, refer Table 12). It is also assumed that no control devices are installed in the restaurants to control the emissions.

**Table 12 Emission factors (g/kg) for the Hotels/Restaurants (Source: CPCB, 2011)**

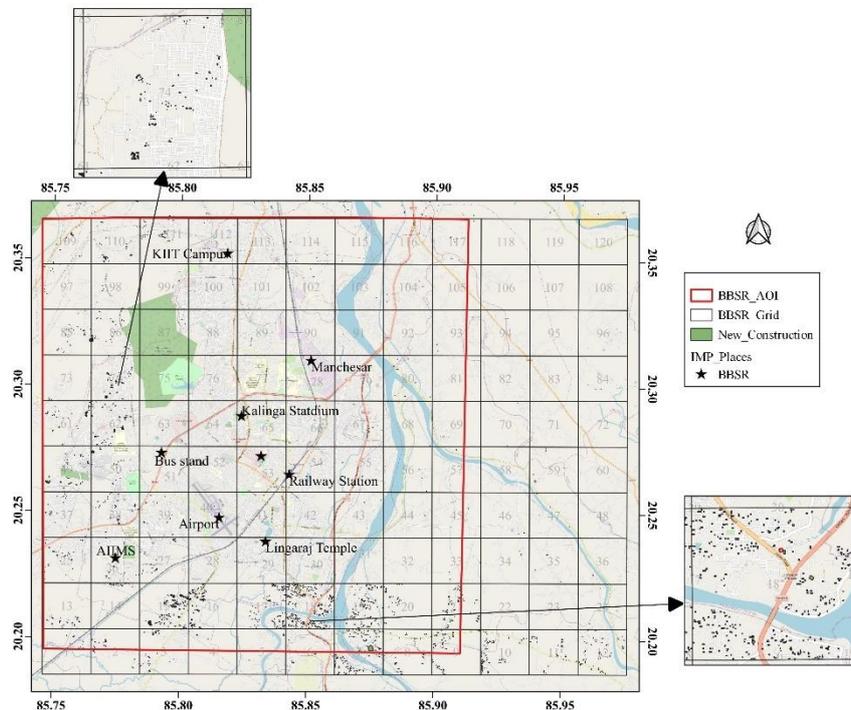
Fuel	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>x</sub>	CO	NMVOCs
Coal	14	8.4	13.3	3.99	24.92	9
LPG	2.1	2.1	0.4	1.8	0.252	10.5
Wood	17.3	12.1	0.2	1.3	126.3	0.01

### 3.4.7. Construction

The PM emissions from construction sector are estimated on the basis of total area under construction in the study area for the specified baseline year. The construction area is determined using the satellite imaging on Google Earth. To determine the newly constructed areas in each grid, satellite images in two different time frames (i.e. January, 2022 vs November/December, 2022) are visually/manually compared. The newly constructed buildings were marked using polygon tool in Google earth application. Fig. 67 shows the map of construction locations identified using the satellite imagery. The emissions are obtained by using equation 13.

$$E = A_s \times EF \dots \dots \dots \text{Eq. (13)}$$

Where, E is Total PM Emissions;  $A_s$  is total construction area and EF is Emission Factors (USEPA). The emissions from construction activities will be estimated using PM emission factor of 1.2 tons/acre/month of activity provided by EPA. As per a recent study by The Energy & Resources Institute (TERI, 2016) in Surat, PM<sub>10</sub> and PM<sub>2.5</sub> emissions from construction areas are approximately 25% and 6% of the total PM mass.



*Figure 67 Map showing construction areas identified using the satellite imagery in Bhubaneswar region. The inset view shows zoomed in view of new construction activities in grid no. 18 and 74 of the study domains.*

### 3.4.8. Diesel Generators

The diesel generators are commonly used in the case of power failures and are considered as an important source of air pollution. The primary sample data such as installed capacity, fuel consumption, frequency and time of usage, and locations is obtained through primary surveys in localities around 4 sampling sites. The emission factors suggested by CPCB (2011) are used to quantify the emissions originating from industrial diesel generators. The emission factors used for computing emissions from diesel-based generators are presented in Table 13.

*Table 13 Emission factors (kg/kWh) for different pollutants used for diesel generators*

Activity	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>x</sub>	CO	NM VOC
Diesel generator	0.00133	0.001197	0.00124	0.0188	0.00406	0.026857

### 3.4.9. Wind-blown riverbed erosion dust

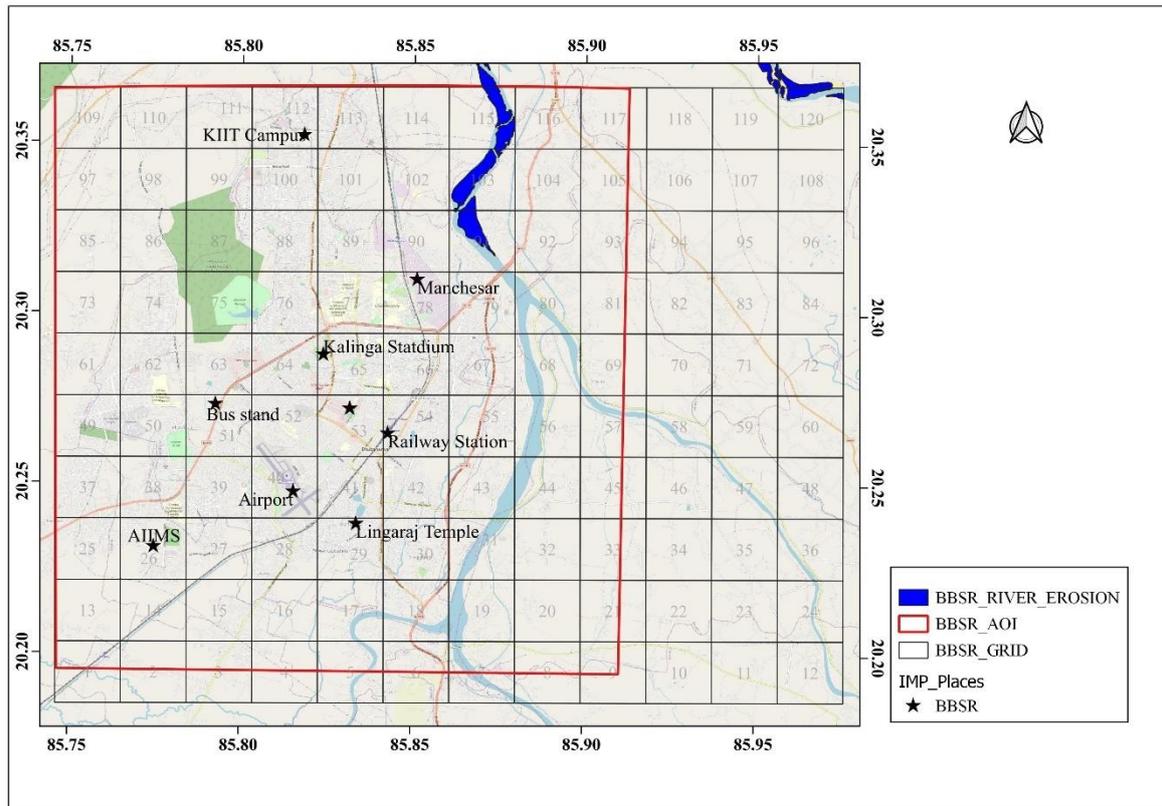
The Kuakhai River, a distributary of the Kathajodi River, originates near Mundamuhan village and flows along the city of Bhubaneswar. It branches into the Daya and Kushabhadra Rivers near Baliana village, covering an approximate distance of 18 km from its origin at the Kathajodi to its bifurcation. During the summer season, the riverbeds become dry, leading to the mobilization of sand particles by wind. These airborne particles contribute to particulate matter emissions, with their impact on air pollution dependent on the quantity and dispersal potential of the sand injected into the atmosphere. While large dust particles typically settle close to the source, significant quantities of fine particles are also emitted and can disperse over greater distances.

In the present study, the riverbed erosion dust emissions are calculated using the concept of friction velocity (UESPA, 2006a). When the actual friction velocity ( $u^*$ ) at a site exceeds the threshold friction velocity ( $u_t$ ), the erosion is expected to occur. In this study, the meteorology data i.e. hourly average wind speed data (10 m) is used to calculate the frictional velocity. For riverbed sand particles, threshold friction velocity ( $u_t$ ) is assumed to be 0.2 m/s. Emission flux of erosion dust is estimated as a function of surface frictional velocity and soil texture. The relationships developed by Alfaro and Gomes (2001) for the soil with sandy texture is applied to estimate dust emission fluxes. The PM<sub>10</sub> emission factor (g/cm<sup>2</sup>/s) for wind-generated

particulate emissions can then be calculated using equation 14. The PM<sub>2.5</sub> emissions are calculated using a ratio of 1/4.

$$EF_{PM10} = 1.24 \times 10^{-7} \times u_*^{3.44} \dots \dots \dots Eq. (14)$$

The potential dry riverbed area marked in GIS (Refer Fig. 68), is then multiplied by emission factors to get the PM emissions from riverbed erosion.



*Figure 68: Map showing potential dry riverbed area (marked in blue colored polygons) in Bhubaneswar region and surrounding areas digitized using Google Earth Applications*

### 3.4.10. Industries

Bhubaneswar is the state capital and there are no air polluting industries within the study domain. As per the data collected from Bhubaneswar regional office of State Pollution Control Board (OSPCB), there are a few industrial units which include food processing and textile units. The collected data included data on manufacturing process, stack dimensions, fuel usage, installed control equipment and stack emissions of pollutants. Industrial stacks emissions are

not routinely monitored in the small-scale units; hence emissions are estimated based on the fuel usage.

### 3.4.11. Brick Kilns

Brick kilns are an important source of air pollution, especially in the peripheral areas of the urban centres. This study used latest available satellite imagery to locate and identify the operational brick kilns over the study domain. The study domain has 13 number of brick kilns and all of them are Fixed Chimney Bull’s Trench Kiln (FCBTK) type. Fig. 69 shows the locations of brick kilns in the study area. The data on production capacity, operation pattern, fuel usage was generated based on personal interactions with the kiln operators.

The production-based approach is used to estimate the brick kilns emissions. In this method, emissions are estimated based on tonnes of bricks produced annually. The emission factors are provided in Table 14. The total emissions from brick kilns calculated using Eq. 15

$$E_p = W_b \times EF \dots \dots \dots (15)$$

Where,  $E_p$  Stands for emissions of particular pollutant,  $W_b$  is weight of annual production of bricks and  $EF_p$  is the emission factor for a particular pollutant.

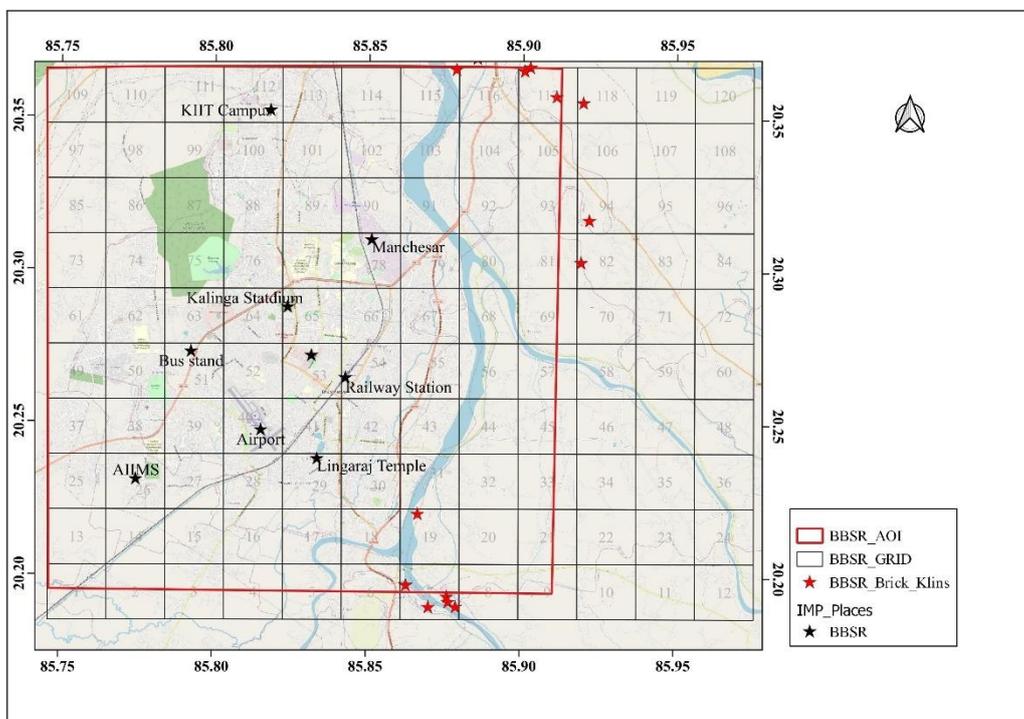


Figure 69 Map showing locations of brick kilns in the Bhubaneswar study domain identified using satellite imagery

**Table 14 Emission Factors (g/kg) for different technology brick kilns**

Technology	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>x</sub>	CO	NM VOC
FCBTK	0.875	0.18	0.59	0.00005	2.94	0.1
Clamp	1.3	1	0.3	0.00015	10	0.15
Zig-zag	0.26	0.13	0.32	0.00004	1.47	0.1

### 3.4.12. Crematoria

Cremating the bodies of dead people is an ancient ritual and practice in India. The total emissions from cremation calculated using Eq. 16.

$$E_p = F_b \times EF_{f,p} \dots \dots \dots (16)$$

Where, E<sub>p</sub> is the emission of a particular pollutant p, F<sub>b</sub> is the amount of fuel used per body in the crematoria, EF<sub>f,p</sub> is Emission factor for pollutant p. The average number of dead bodies cremated each month is calculated based on crude death rate of Khordha district.

In addition to number of dead bodies cremated, the data also include type of fuel used viz. wood, electricity, gas, and cow dung cakes. The emission factors for wood burning at crematoria are taken from Akagi et al. (2011) and Sharma et al. (2016) and listed below in Table 15. The emissions are quantified using equation 14.

**Table 15: Emission Factors for crematoria (g/body)**

Fuel	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>x</sub>	CO	NM VOCs
Wood (g/body)	5550.0	2730.0	120.0	750.0	27900.0	15,570.0
Electricity (g/body)	3.60	2.25	3.60	26.1	18.0	171.0

### 3.4.13. Aviation

Emissions from aircrafts have been estimated for the domestic and international flight movement at Biju Patnaik International Airport, Bhubaneswar. It is located on the southern part of the city. Emissions from aircrafts are calculated from the aircraft movements in a Landing and Take-off (LTO) cycle. 2 aircraft movements constitute 1 LTO cycle and emissions are calculated using Eq 17.

$$E_p = N_{LTO} \times EF_p \dots \dots \dots (17)$$

Where, E<sub>p</sub> is the emission of a particular pollutant p, NLTO is the average number of landing and take-off (LTO) cycles per day, and EF<sub>p</sub> is Emission factor for pollutant p.

The data on monthly flight movements at Biju Patnaik International Airport in year 2022 is obtained from Airport Authority of India (<https://www.aai.aero/en/business-opportunities/aai-traffic-news>). This data was converted to number of LTO cycle per day and emission factors listed in Table 16 are used to calculate the aircraft emissions. The emissions from aircraft are allocated only to grids covering the airport area.

**Table 16: Emission Factors (kg/LTO) for aviation sector**

	PM	SO <sub>2</sub>	CO	NO <sub>x</sub>	NMVOCs
Emission Factor	0.27	1.54	39.5	19.11	20.38

(Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories  
Aircraft Emissions)

### 3.5. Uncertainty in Emission Estimates

In this study, the uncertainties are quantified using uncertainty aggregation method prescribed by EMEP and IPCC (2006). Uncertainty aggregation method is used to propagate the uncertainty introduced by activity data (AD) and emission factors (EFs) to any combination/aggregation of sources. Analyses are conducted for the emission baseline year 2022 for pollutants including PM10, PM2.5, SO<sub>2</sub>, NO<sub>x</sub>, and CO.

Primarily, the uncertainty in emission estimates is a function of the uncertainty of input data i.e. activity and emission factors, used to compile the inventory. The uncertainty in the AD ( $u_{AD}$ ) collected from authorities, local administration and primary surveys is mainly of a statistical nature, stemming from incompleteness, representativeness of sampling, the imputation of missing data, and extrapolation (Rypdal and Winiwarer, 2001; Olivier, 2002; IPCC, 2006; Solazzo et al., 2021). The urban level statistics and data are believed to be comparatively more reliable and robust than the rural and other areas. Hence, the sector-wise activity data uncertainties for urban or city areas and other areas are calculated, separately.

The uncertainty in the EF ( $u_{EF}$ ) has many sources – for example, the degree of representativeness of the limited number of observations underlying the EF, including the under-representativity of operating conditions, the inaccuracy of assumptions and/or of source aggregation, bias, variability, and/or random errors (IPCC, 2006; Solazzo et al., 2021).

As per method prescribed by IPCC (IPCC, 2006), the emission uncertainty ( $u_E$ ) is the sum of the squares of the uncertainty of activity data ( $u_{AD}$ ) and the uncertainty of emission factors ( $u_{EF}$ ; Eq. (18)). It is assumed that uncertainties of different source categories are uncorrelated (e.g. industries and waste burning).

$$u_E = \sqrt{u_{AD}^2 + u_{EF}^2 \dots \dots \dots} \text{Eq. (18)}$$

The uncertainty estimates are provided along with baseline emission inventory estimates in section 3.7.

### 3.6. Exclusion of sectors in emission inventory

As described previously, this study has considered \_\_ source sectors in development of emission inventory for the Bhubaneswar-Cuttack region. Although, the sectors listed above represent regional emissions in Bhubaneswar-Cuttack region adequately; there are certain sectors which are not considered in this study. This section presents a brief discussion on excluded sectors/sources of air pollution in the present emission inventory.

#### 3.6.1. Agricultural burning and forest fires

Agricultural burning and forest fires are considered as an important source of air pollution in the regional context of many Indian cities. A preliminary analysis of satellite derived fire counts and Fire Radiative Power (FRP) is conducted over the study domain for the baseline year 2022. The analysis was conducted using VIIRS Soumi NPP fire data, downloaded from NASA's Fire Information for Resource Management System (FIRMS; <https://firms.modaps.eosdis.nasa.gov/>). The downloaded data in shapefile format was pre-processed to remove any false fire counts observed over Industrial stacks in the Bhubaneswar-Cuttack region. Annexure G-6 depicts the time series plot of daily fire counts observed during year 2022 over Bhubaneswar-Cuttack study domain. As shown in Annexure G-6, the daily fire incidents/counts over study domain are very low, reaching maximum upto 10, during summer months. These fire incidents are mainly observed over the forest areas located on the western part and isolated places on the outskirts of the study domain. Considering insignificant numbers and intensity of fire incidents over study domain, the emissions from such activities are excluded from the regional inventory.

Although the present study has not considered emissions from agricultural burning and forest fires, it is recommended to include these emissions while analysing the air quality at a

larger scale. For example, analysis involving mesoscale photochemical modelling and long-range transport analysis.

### **3.6.2. Rail transport**

The emissions from Railway operations are not considered in this study. During the initial discussion with stakeholders and literature review, it was learned that railway operations in the region are mainly electricity-based and may not constitute to local/regional emissions.

### 3.7. Sectorial Emission Inventory

#### 3.7.1. Transport

Figure 70 shows the emissions of pollutants originating from transport sector in Bhubaneswar region. It can be seen that CO is the maximum contributing pollutant from transport sector in Bhubaneswar with emissions of 38,788 tonnes per year, followed by NMVOCs (25,401 tonnes per year), and NO<sub>x</sub> (13,029 tonnes per year). Transport sector contribution to regional PM<sub>10</sub> and PM<sub>2.5</sub> emissions was found to be 1575 and 1417 tonnes per year, respectively. It is important to note that, the vehicular exhaust PM emissions predominantly consist of fine particles i.e. particles having aerodynamic diameter less than or equal to 2.5 µm (Ketzel et al., 2007). Following the approach suggested by Sharma and Dikshit (2016), PM vehicular exhaust emission factors are used directly for quantifying PM<sub>10</sub> while PM<sub>2.5</sub> fraction is assumed to be 90% of PM<sub>10</sub> emissions.

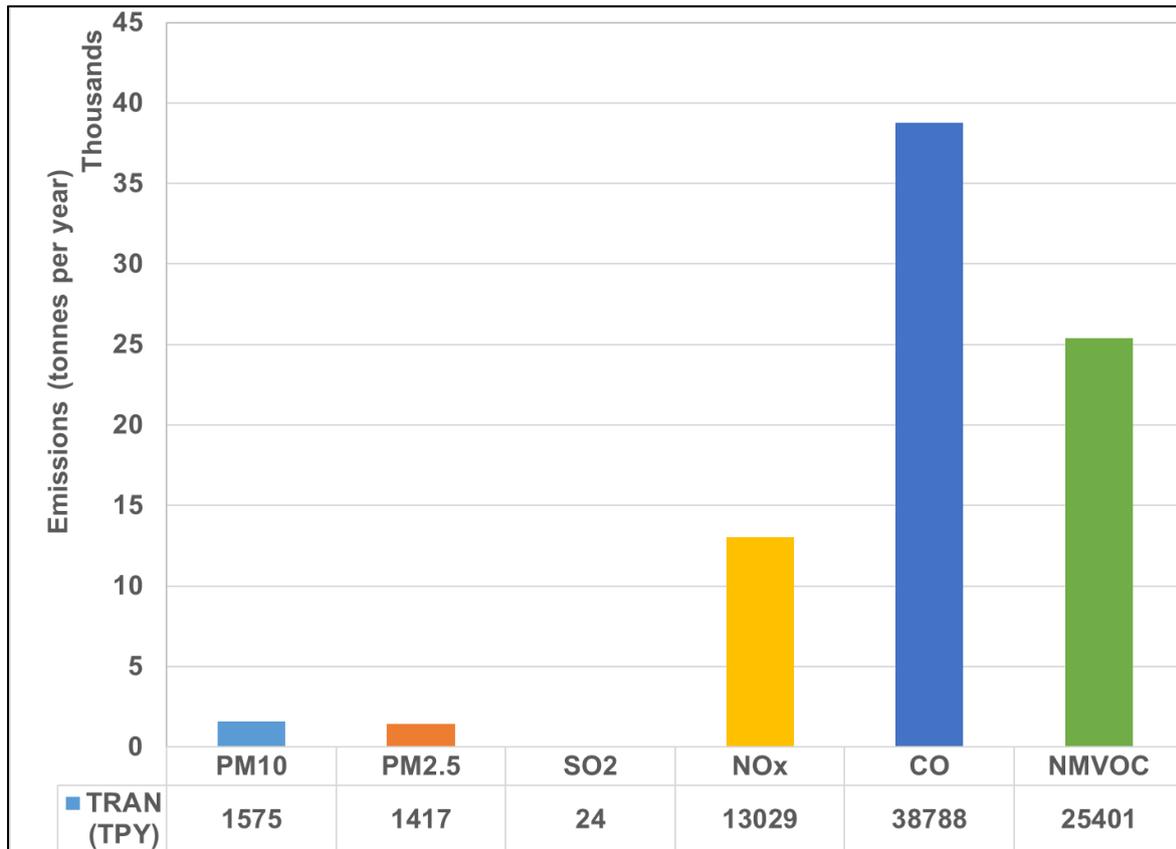


Figure 70: Emission loads (tonnes per year) of pollutants originating from the transport in Bhubaneswar region

### 3.7.2. Road dust resuspension

The PM emissions generated due to road dust re-suspension in Bhubaneswar region are depicted in Fig. 71. The road dust contributes only to particulate matter and not the gaseous pollutants. The road dust primarily contributes to the coarse fraction of PM i.e. PM<sub>10</sub> and emissions are estimated to be 3,021 tonnes per year. The fine fraction i.e. PM<sub>2.5</sub> emissions are estimated to be 731 tonnes per year in 2022. PM<sub>2.5</sub> emissions from road dust re-suspension are about four times lower than PM<sub>10</sub> emissions.

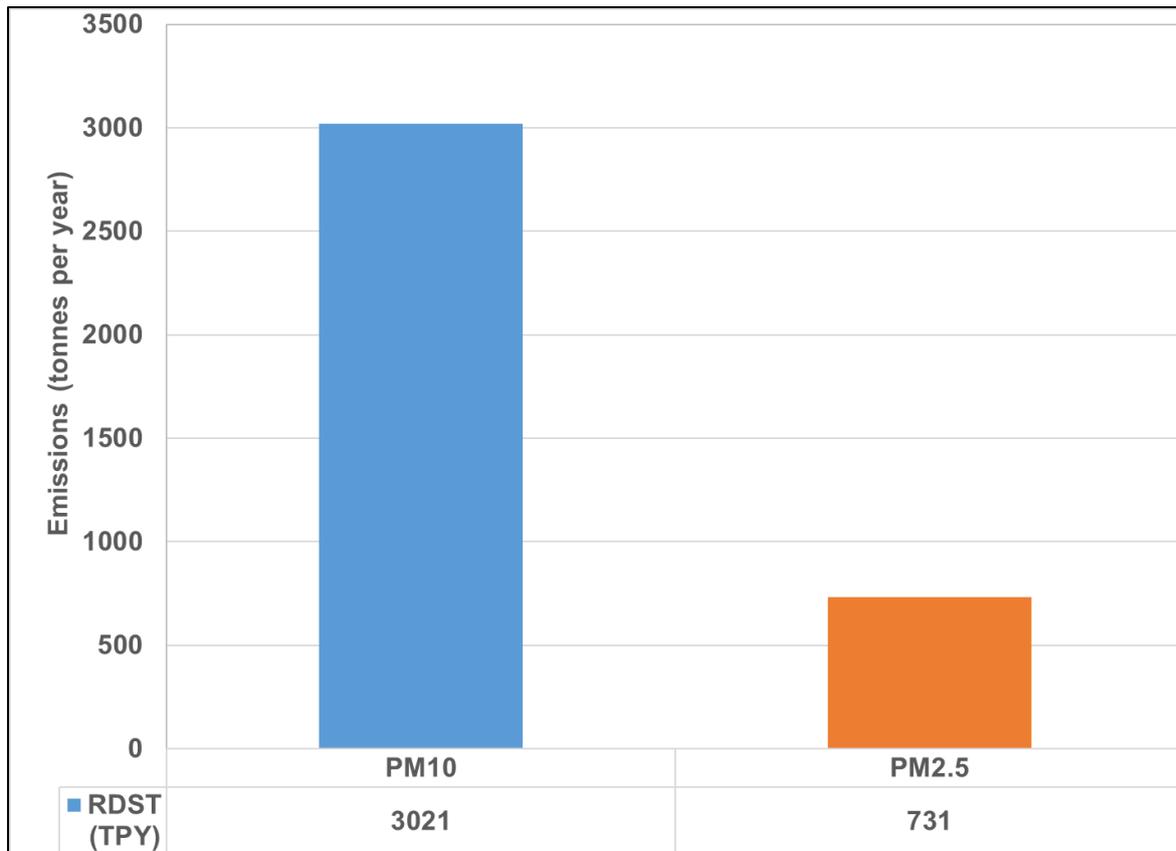


Figure 71: Emission load (tonnes per year) of pollutants originating from the road dust resuspension sector in Bhubaneswar region

(Note: Emission loads for pollutants other than PM<sub>10</sub> and PM<sub>2.5</sub> are “NOT APPLICABLE”)

### 3.7.3. Residential

Figure 72 depicts the emission loads originating from residential sector in Bhubaneswar region. The residential sector emissions are largely attributed to use of wood and coal as fuel for cooking and heating applications. Although LPG connections are available with individual households, the gas refilling is avoided citing the higher costs involved. Further, wood and coal are easily and cheaply available in surrounding areas. Due to incomplete combustion of solid fuels, CO is found to be the major pollutant from residential sector with annual emissions of 6946 tonnes per year, followed by NMVOCs (2271 tonnes per year), PM<sub>10</sub> (767 tonnes per year), PM<sub>2.5</sub> (488 tonnes per year), SO<sub>2</sub> (429 tonnes per year) and NO<sub>x</sub> (298 tonnes per year).

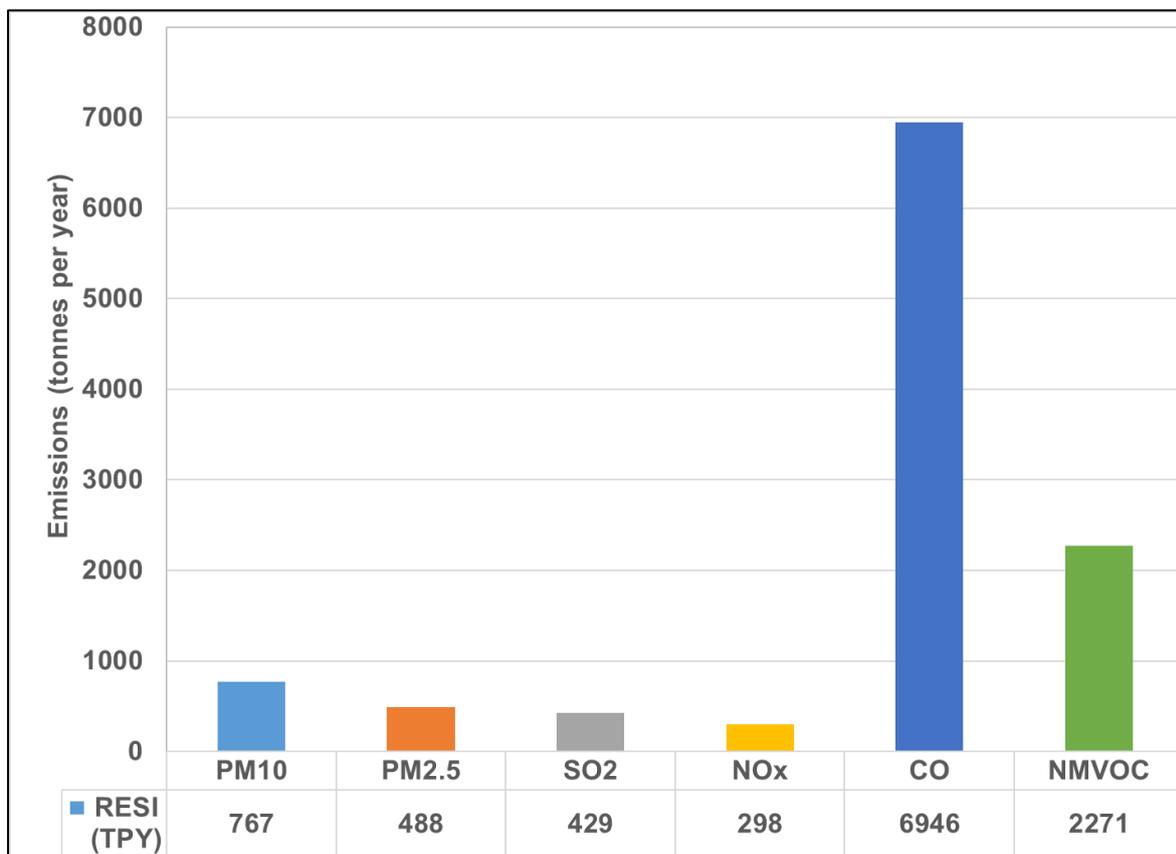


Figure 72: Emissions load (tonnes/year) of pollutants originating from residential sector in Bhubaneswar region

### 3.7.4. Open waste burning

Figure 73 presents the emissions of air pollutants originating from open waste burning in Bhubaneswar region. It is observed that, due to incomplete combustion of the waste a large amount of CO would be introduced into the atmosphere (4242 tonnes per year) followed by NMVOCs (918 tonnes per year), PM<sub>10</sub> (886 tonnes per year), PM<sub>2.5</sub> (823 tonnes per year), NO<sub>x</sub> (127 tonnes per year) and SO<sub>2</sub> (56 tonnes per year).

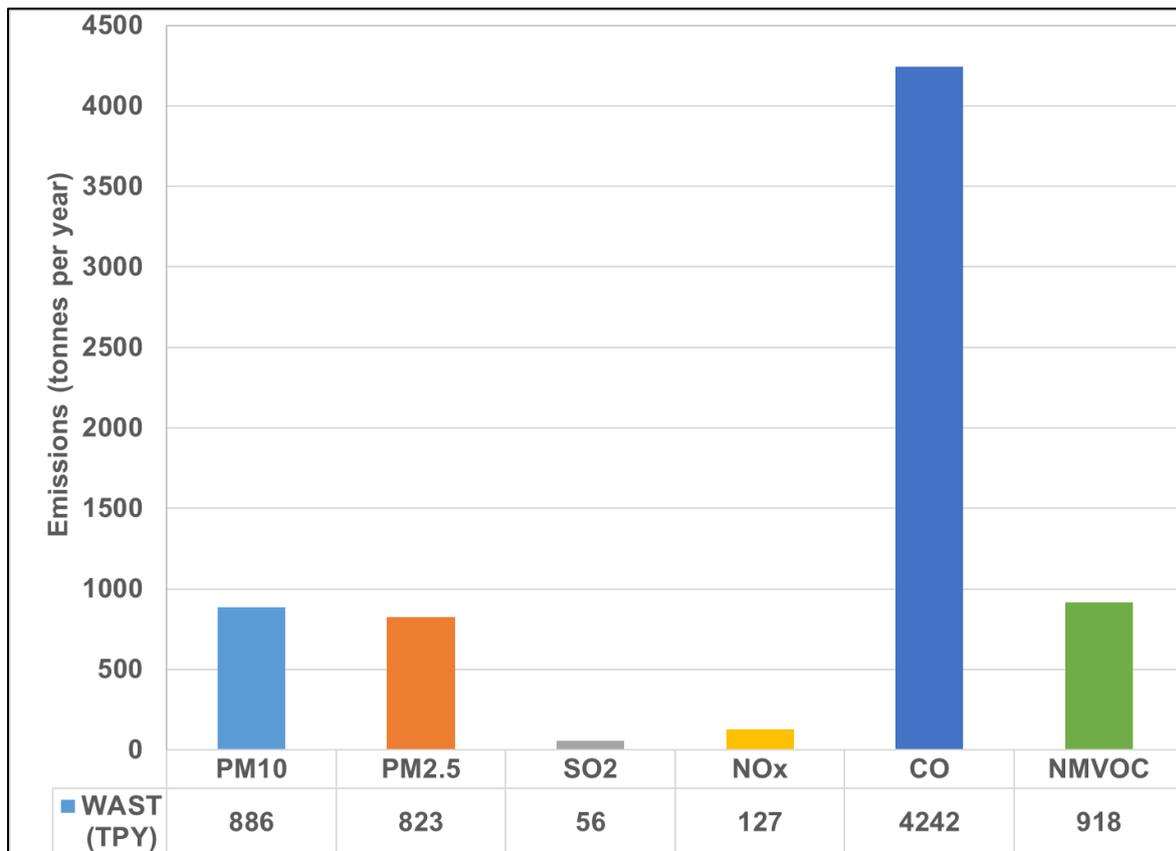


Figure 73 Emission load (tonnes per year) of pollutants originating from the open waste burning sector in Bhubaneswar region

### 3.7.5. Hotels, restaurants and bakeries

Figure 74 presents the emissions load contributed by hotels, restaurants, bakeries and open eateries in Bhubaneswar region. CO has been found to be the major contributor 3062 tonnes per year, followed by, PM<sub>10</sub> (741 tonnes per year), PM<sub>2.5</sub> (492 tonnes per year), NMVOC (430 tonnes per year), SO<sub>2</sub> (369 tonnes per year) and NO<sub>x</sub> (164 tonnes per year).

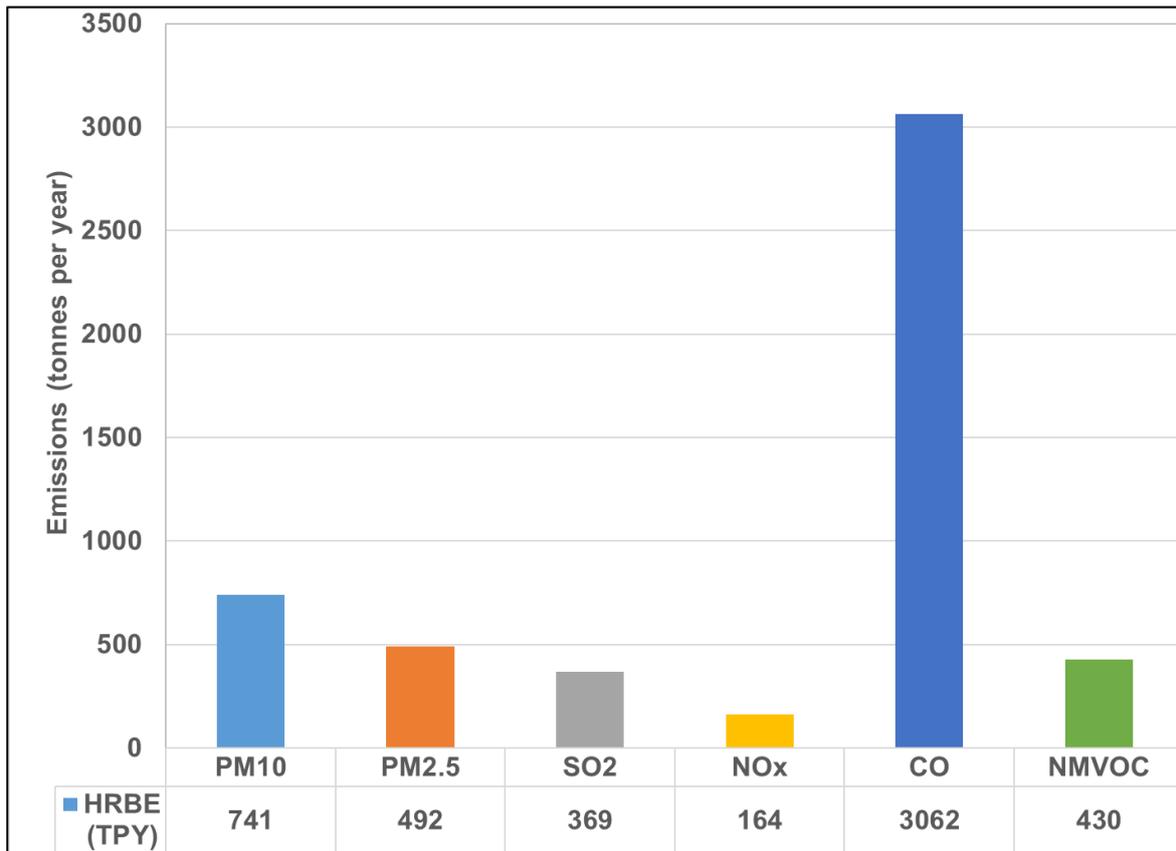


Figure 74: Emissions load (tonnes per year) of pollutants originating from hotels, restaurants and bakeries in Bhubaneswar region

### 3.7.6. Construction

Figure 75 shows the PM<sub>10</sub> and PM<sub>2.5</sub> emissions originating from construction activities in Bhubaneswar region. Construction sector is estimated to contribute about 297 tonnes per year of PM<sub>10</sub> and 74 tonnes per year of PM<sub>2.5</sub>.

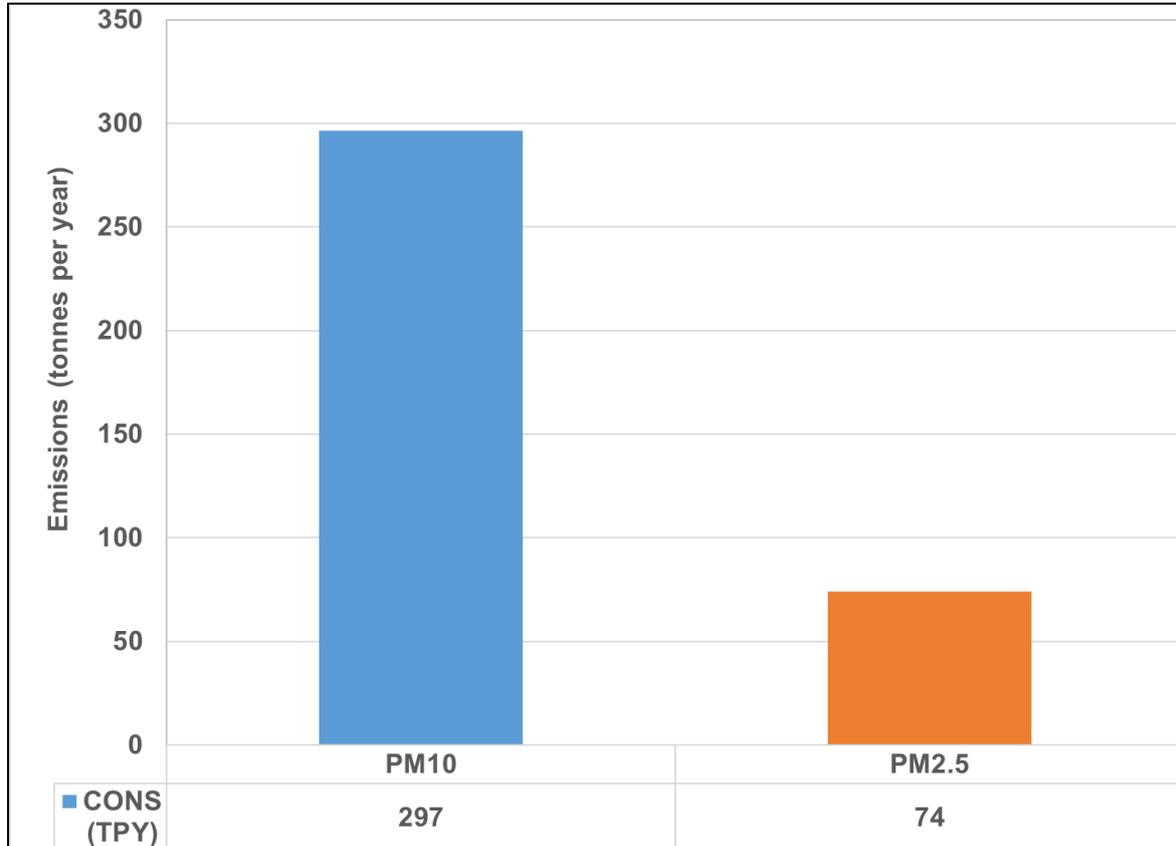


Figure 75: Emissions load (tons/year) of pollutants originating from construction activities in Bhubaneswar region

(Note: Emission loads for pollutants other than PM<sub>10</sub> and PM<sub>2.5</sub> are “NOT APPLICABLE”)

### 3.7.7. Diesel generators

As discussed earlier, diesel generators are only used during the power failure emergency but can significantly contribute to ambient air pollutants. Figure 76 shows emissions of pollutants originating from diesel generators usage in Bhubaneswar region. NMVOC is the major contributor (4265 tonnes per year) from diesel generators, followed by NO<sub>x</sub> (3257 tonnes per year), CO (703 tonnes per year), PM<sub>10</sub> (347 tonnes per year), PM<sub>2.5</sub> (299 tonnes per year), SO<sub>2</sub> (215 tonnes per year).

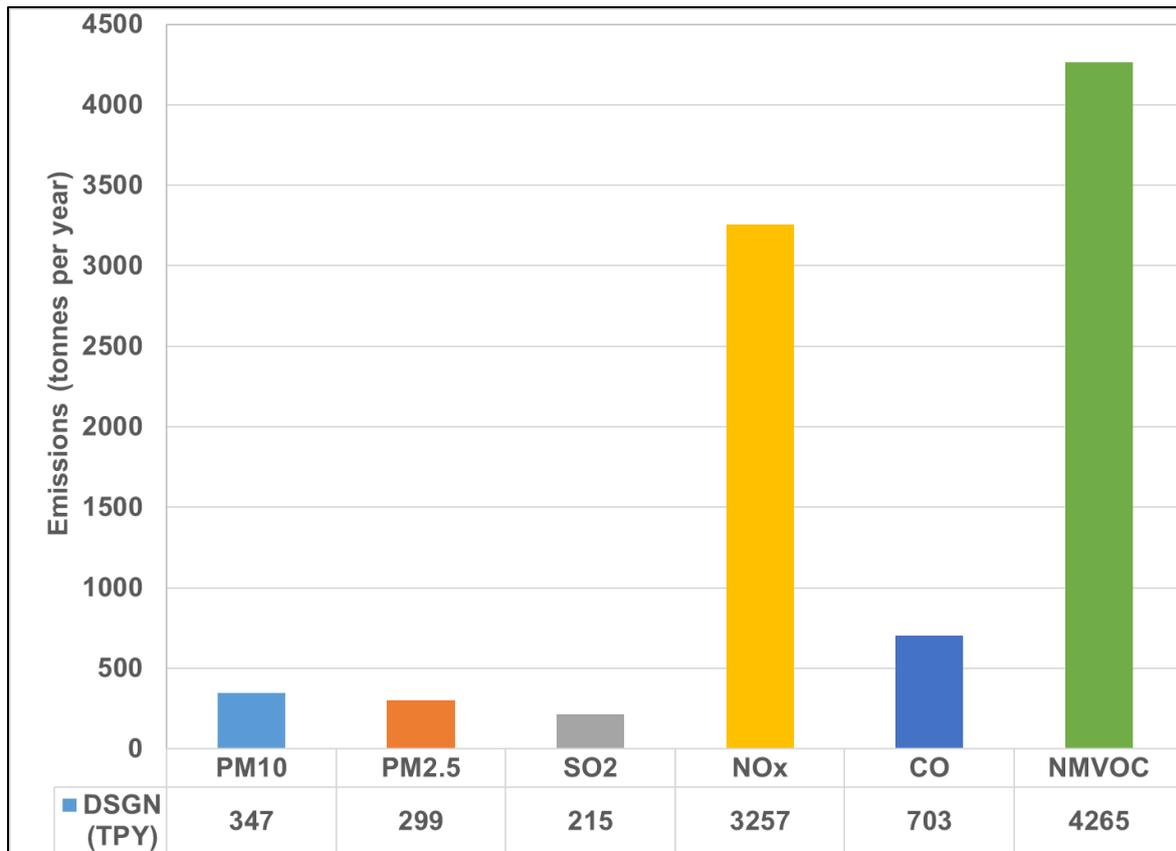


Figure 76 Emissions load (tonnes per year) of pollutants originating from diesel generators usage in Bhubaneswar region

### 3.7.8. Wind-blown riverbed erosion dust

The wind-blown riverbed erosion dust emissions are estimated using friction velocity method. These emissions are generally released close to surface, thereby increasing their relative contributions to ambient particulate matter. Figure 77 shows the wind-blown riverbed erosion dust emissions load originating from Bhubaneswar region. PM<sub>10</sub> was estimated to be 12 tonnes per year, followed by PM<sub>2.5</sub> (3 tonnes per year).

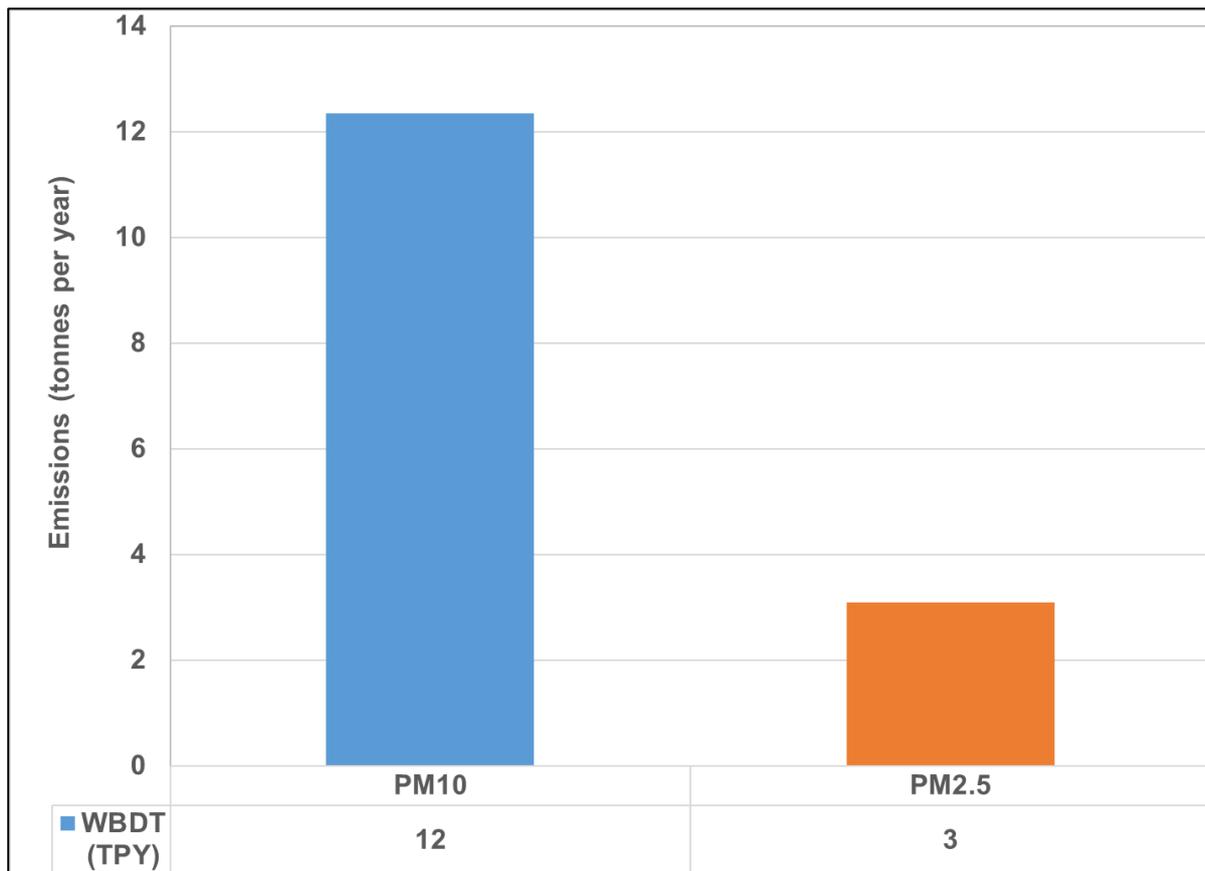
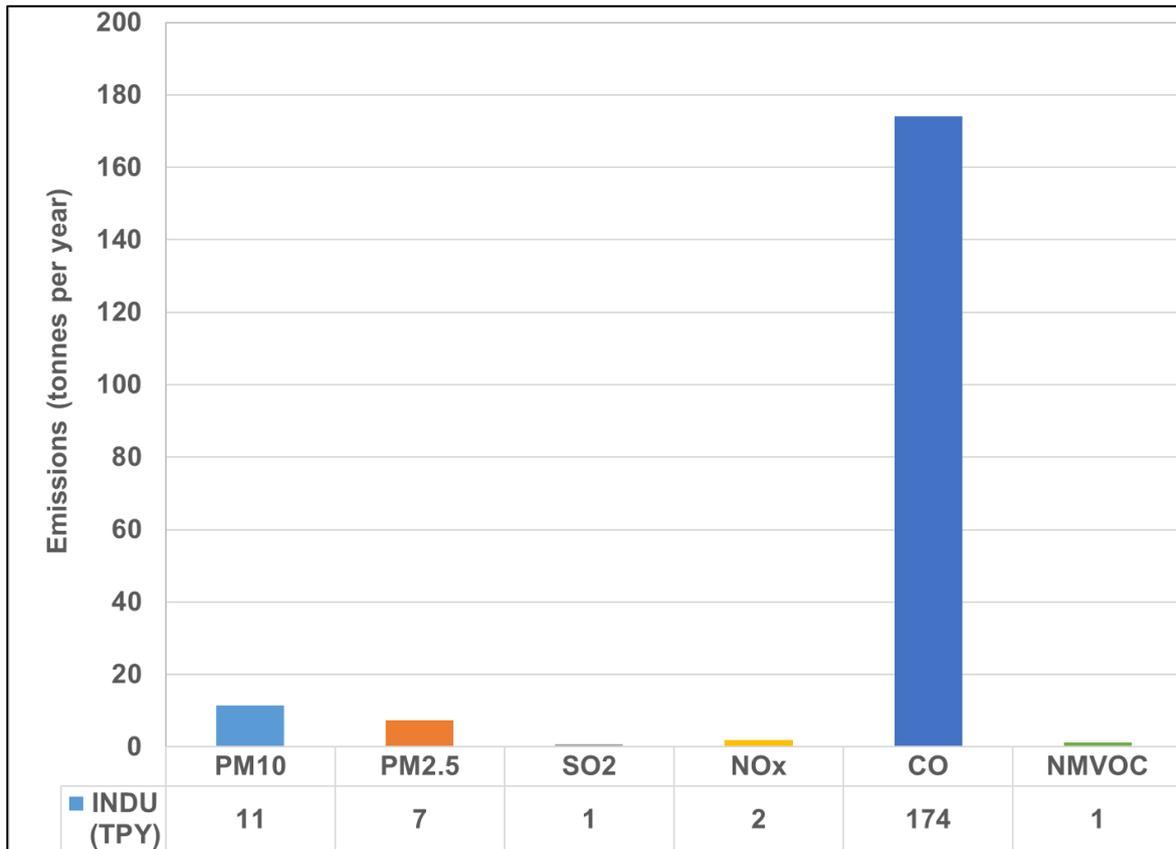


Figure 77: Emissions load (tonnes per year) of pollutants originating from Wind-blown riverbed erosion in Bhubaneswar region

### 3.7.9. Industries

As discussed earlier, Bhubaneswar is not an industrial city and industrial units mainly include food processing and textile units. Figure 78, shows the stack emissions originating from these industries. CO emissions are found to be highest among the industrial pollutants i.e. 174 tonnes per year, followed by PM<sub>10</sub> (11 tonnes per year) and PM<sub>2.5</sub> (7 tonnes per year), NO<sub>x</sub> (2 tonnes per year), SO<sub>2</sub> (1 tonnes per year) and NMVOC (1 tonnes per year).



*Figure 78: Emissions load (tonnes per year) of pollutants originating from industrial sector in Bhubaneswar region*

### 3.7.10. Brick Kilns

Figure 79 shows the emissions of pollutants originating from brick kilns in Bhubaneswar region. CO is the maximum contributor with emissions of 49 tonnes per year, followed by PM<sub>10</sub> (14.74 tonnes per year), SO<sub>2</sub> (10 tonnes per year), PM<sub>2.5</sub> (3 tonnes per year) and NMVOC (2 tonnes per year). NO<sub>x</sub> was found to be lowest contributor with emission of less than 0.1 tonnes per year.

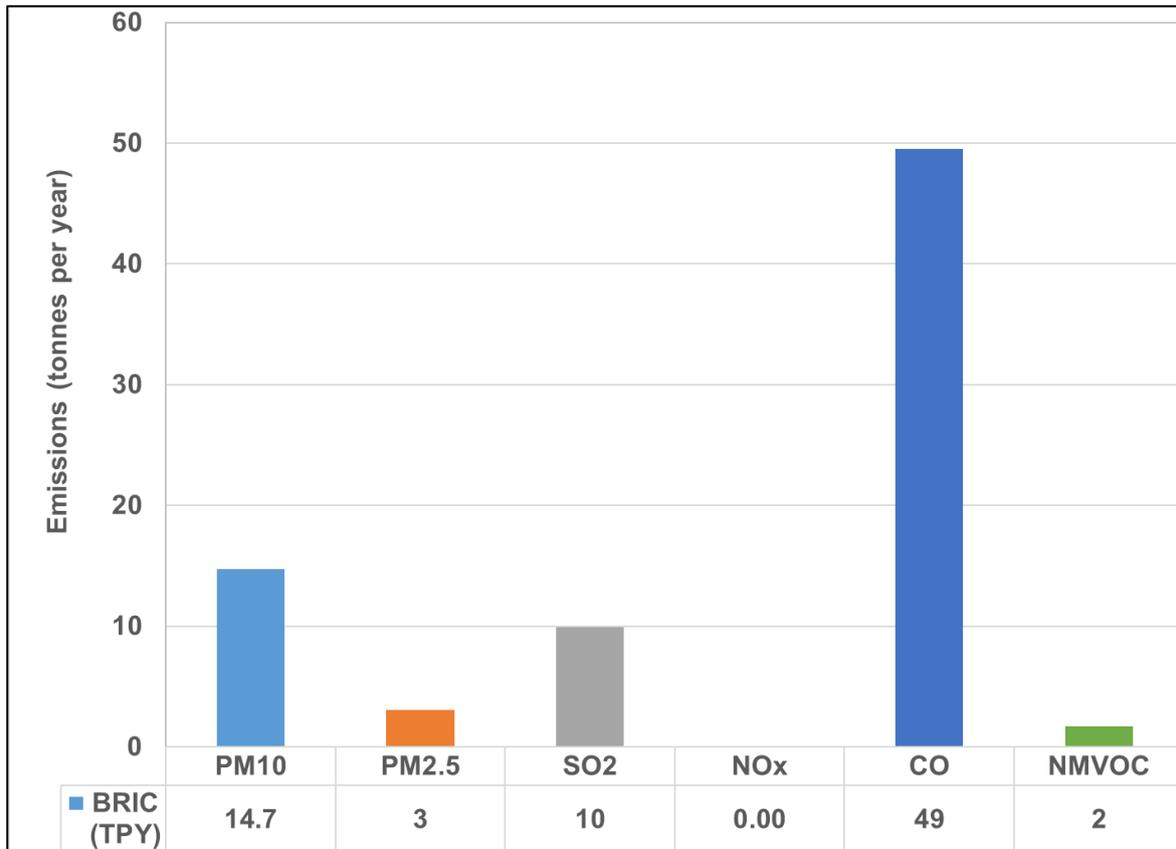


Figure 79 Emissions loads (tonnes per year) of pollutants originating from brick kilns in Bhubaneswar region

### 3.7.11. Crematoria

Figure 80 shows the emissions of pollutants originating from cremation activities in Bhubaneswar region. Due to incomplete combustion of wood in wood pyres, CO is the maximum contributor with emissions of 196 tonnes per year, followed by NMVOCs (109 tonnes per year), PM<sub>10</sub> (39 tonnes per year) and PM<sub>2.5</sub> (19 tonnes per year). NO<sub>x</sub> was found to contribute 5 tonne per year of emissions, while SO<sub>2</sub> was found to be the lowest among all pollutants with less than 1 tonnes per year of emissions.

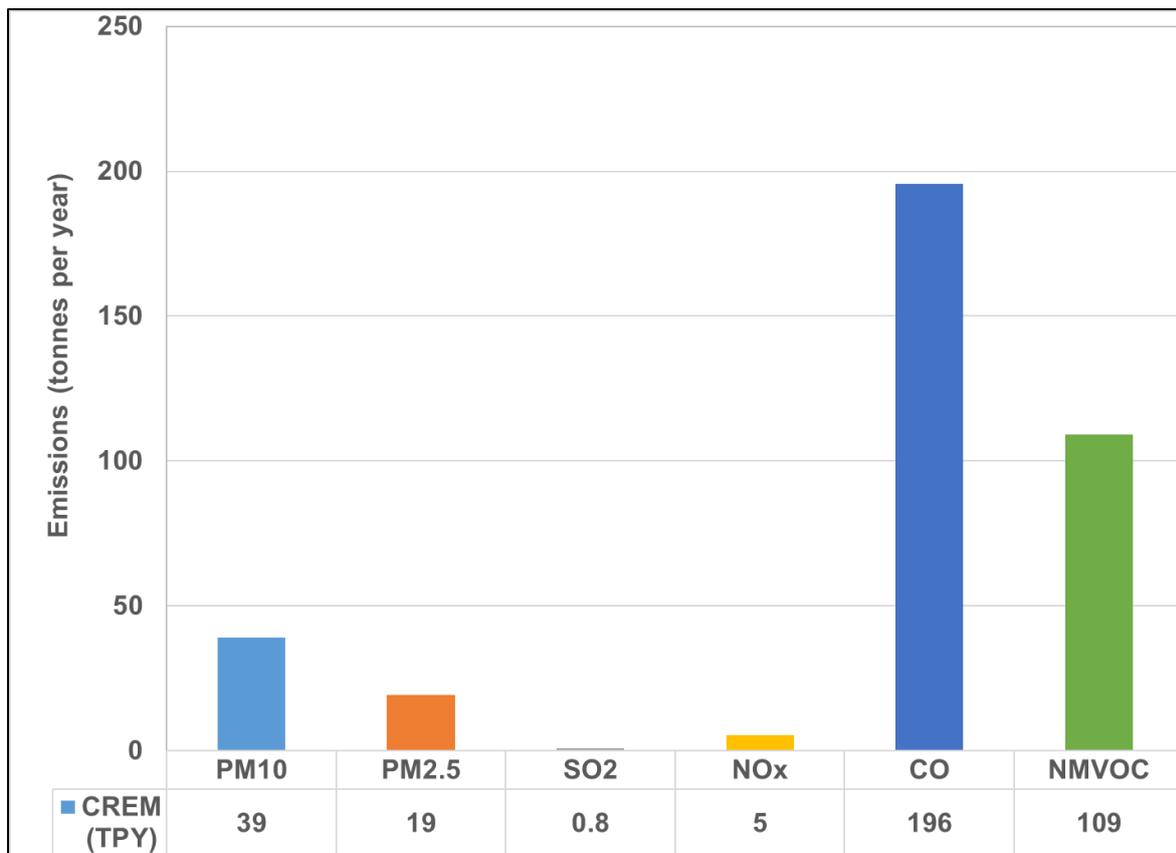


Figure 80 Emissions loads (tonnes per year) of pollutants originating from crematoria in Bhubaneswar region

### 3.7.12. Aviation

Figure 81 shows the emissions load originating from aviation sector due to flight operations at Biju Patnaik International Airport in Bhubaneswar city. CO was estimated to be highest among the aviation emissions, with 0.537 tonnes per year, followed by NMVOC (0.277 tonnes per year), and NO<sub>x</sub> (0.260 tonnes per year). SO<sub>2</sub>, PM<sub>10</sub> and PM<sub>2.5</sub> were lowest amongst all pollutants with 0.021 tonnes per year, 0.003 tonnes per year and 0.003 tonnes per year respectively.

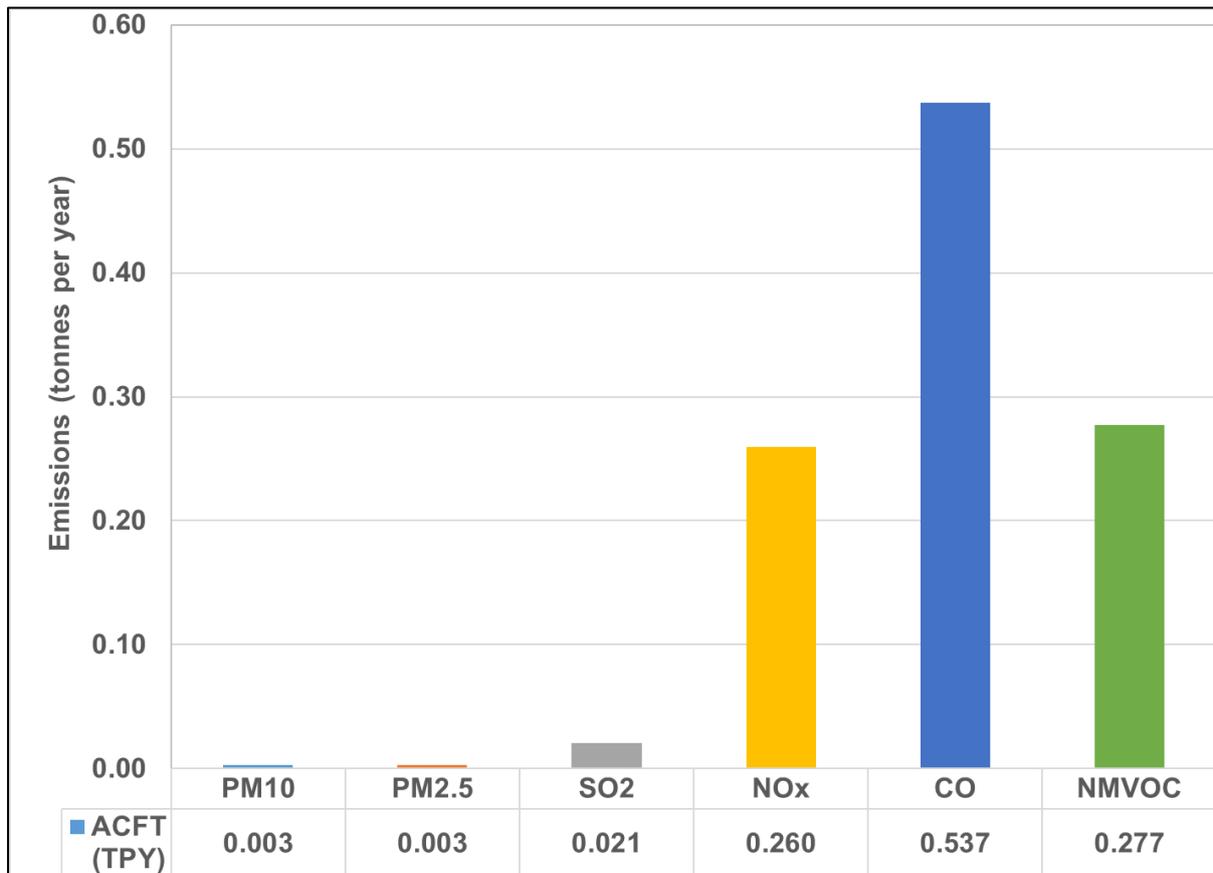


Figure 81: Emissions load (tonnes per year) of pollutants originating from aircraft operations in Bhubaneswar city

### **3.8. Regional Emission Inventory**

The overall baseline emission inventory (Year 2022) for the Bhubaneswar region is presented in Table 17. The sectoral contribution to pollutants is provided in Fig. 82 to 87.

The total PM<sub>10</sub> emission load in the Bhubaneswar region is estimated to be 7,711 tonnes per year. The top four contributors to PM<sub>10</sub> emissions are resuspended road dust (39.2%), followed by transport (20.4%), open waste burning (11.5%), and hotel, restaurants and bakeries (9.6%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable. Daily and seasonal emissions could be highly variable.

PM<sub>2.5</sub> emission load in the Bhubaneswar region is estimated to be 4,356 tonnes per year. The top four contributors to PM<sub>2.5</sub> emissions are transport (32.5%), open waste burning (18.9%), resuspended road dust (16.8%), and hotel, restaurants and bakeries (11.3%). Other PM<sub>2.5</sub> contributors include residential (11.2%), industrial DG (6.9%) and construction (1.7%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

SO<sub>2</sub> emission load in the Bhubaneswar region is estimated to be 1,104 tonnes per year. The top four contributors to SO<sub>2</sub> emissions are residential (38.8%), hotel, restaurants and bakeries (33.4%), industrial DG (19.5%), and open waste burning (5.1%). All Other sectors contributes SO<sub>2</sub> emissions less than 1% except transport (2.1%).

The annual NO<sub>x</sub> emission load in the Bhubaneswar region is estimated to be 16,882 tonnes per year. Transport sector (77.2%) and industrial DG (19.3%) are the largest contributors to NO<sub>x</sub> emissions. Remaining sectors such as residential, hotel, restaurants and bakeries and open waste burning together contributes about 3.6%.

The total annual CO emissions in the Bhubaneswar region are estimated to be 54,162 tonnes per year. The top four contributors to CO emissions are transport (71.6%), residential (12.8%), open waste burning (7.8%), and hotel, restaurants and bakeries (5.7%). All remaining sectors together contribute about 2.1% of total CO emissions in the region.

Fig. 88-92 shows the spatial distribution of pollutants over Bhubaneswar region for baseline year 2022.

**Table 17: Baseline (Year 2022) Emission Inventory for the Bhubaneswar region (tonnes per year) of Odisha**

Sector	PM10	PM2.5	SO <sub>2</sub>	NO <sub>x</sub>	CO	NMVOC
Transport (TRAN)	1575 ± 425	1417 ± 383	24 ± 4	13029 ± 6931	38788 ± 20639	25401 ± 13414
Road dust re-suspension (RDST)	3021 ± 753	731 ± 182	NA	NA	NA	NA
Residential (RESI)	767 ± 397	488 ± 252	429 ± 70	298 ± 154	6946 ± 3602	2271 ± 0
Waste burning (WAST)	886 ± 493	823 ± 458	56 ± 31	127 ± 70	4242 ± 2360	918 ± 1222
Hotels, Restaurants, Bakeries and Open eateries (HRBE)	741 ± 401	492 ± 266	369 ± 85	164 ± 88	3062 ± 1660	430 ± 2296
Construction (CONS)	297 ± 64	74 ± 16	NA	NA	NA	NA
Diesel Generators (DSGN)	347 ± 179	299 ± 154	215 ± 52	3257 ± 1690	703 ± 364	4265 ± 219
Wind-blown Riverbed Erosion dust (WBDT)	12 ± 3	3 ± 0	NA	NA	NA	NA
Industries (INDU)	11 ± 2	7 ± 1	1 ± 0	2 ± 0	174 ± 35	1 ± 0
Brick Kilns (BRIC)	15 ± 8	3 ± 1	10 ± 5	0 ± 0	49 ± 28	2 ± 1
Crematoria (CREM)	39 ± 19	19 ± 9	0.8 ± 0	5 ± 2	196 ± 100	109 ± 1
Aviation (ACFT)	0.003 ± 0	0.003 ± 0	0.021 ± 0	0.259 ± 0	0.537 ± 0	0.277 ± 55
<b>Total</b>	<b>7711 ± 2751</b>	<b>4356 ± 1728</b>	<b>1104 ± 250</b>	<b>16882 ± 8938</b>	<b>54162 ± 28792</b>	<b>33397 ± 17256</b>

Note - “NA” indicates the emissions quantification is not applicable for a particular sector. The value after ± indicates uncertainty in emission estimates (tonnes).

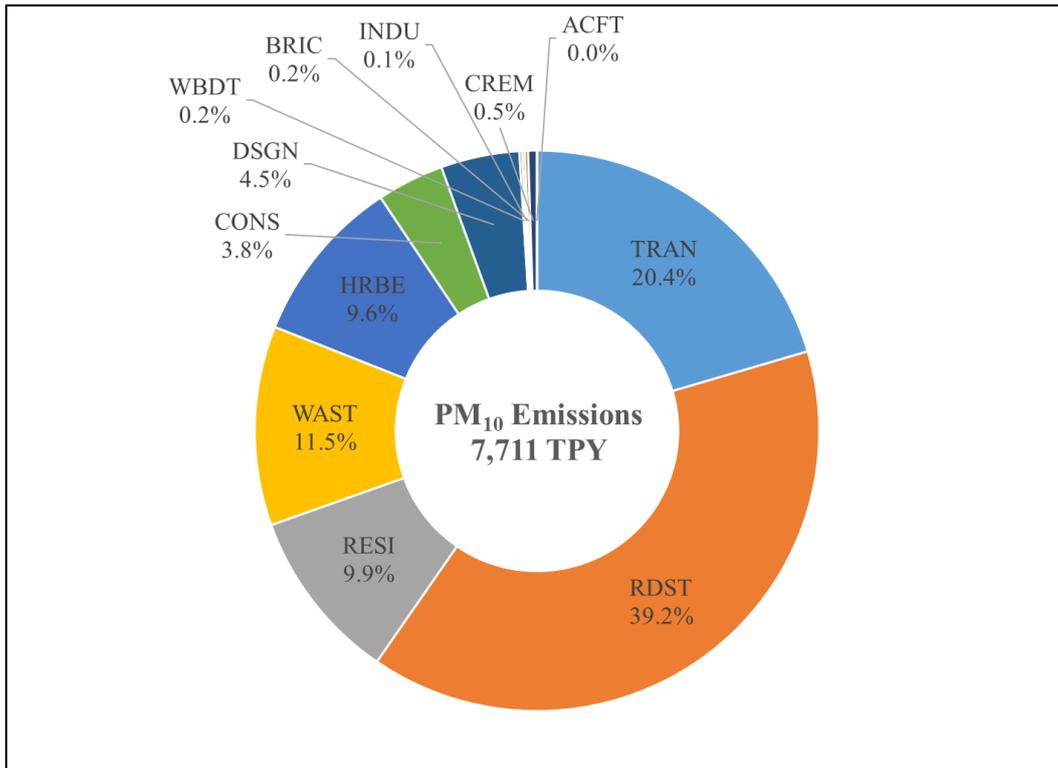


Figure 82 Sectoral contribution to annual PM<sub>10</sub> emissions in Bhubaneswar Region

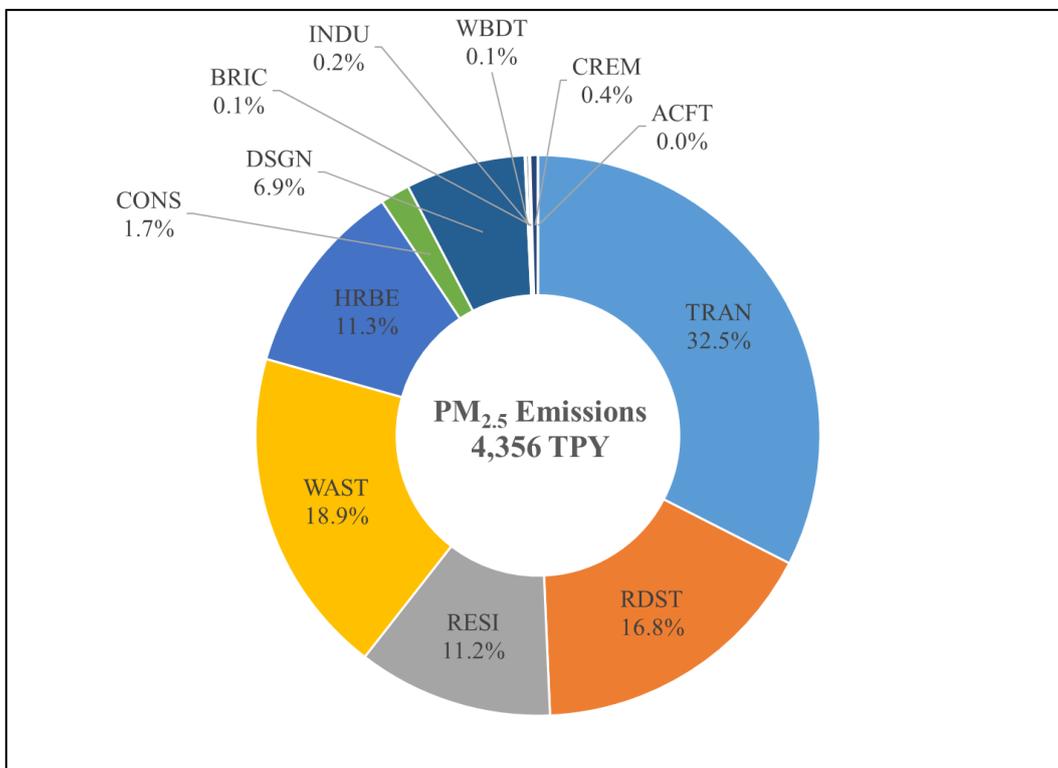


Figure 83 Sectoral contribution to annual PM<sub>2.5</sub> emissions in Bhubaneswar region

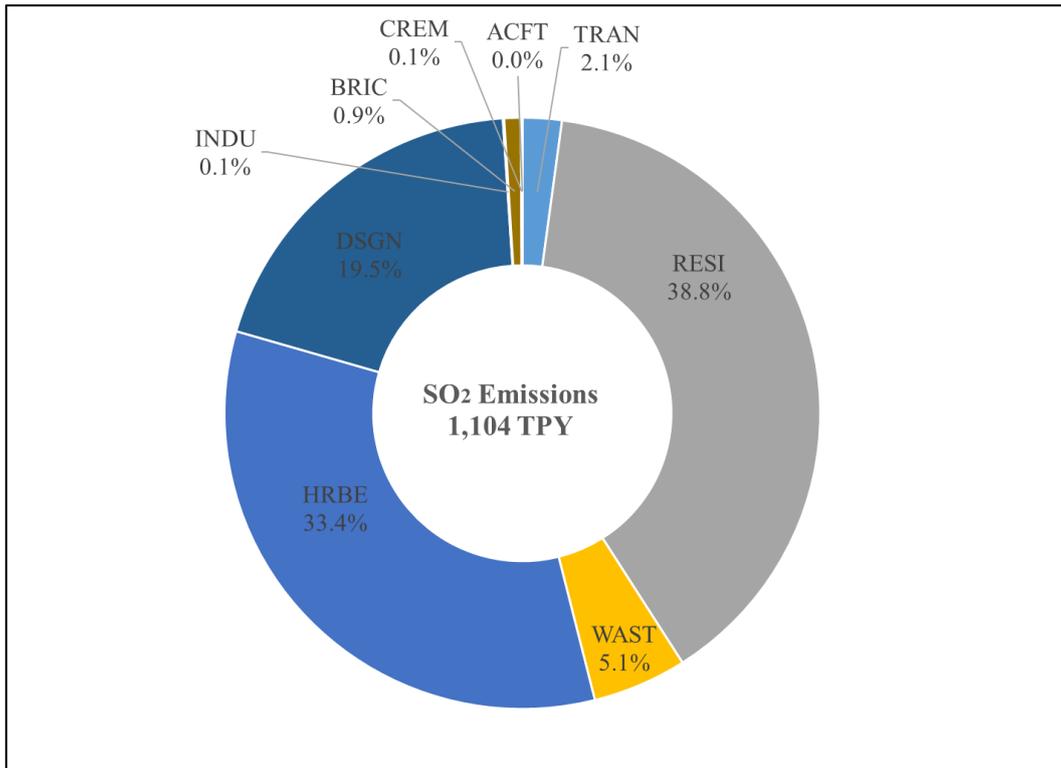


Figure 84 Sectoral contribution to annual SO<sub>2</sub> emissions in Bhubaneswar region

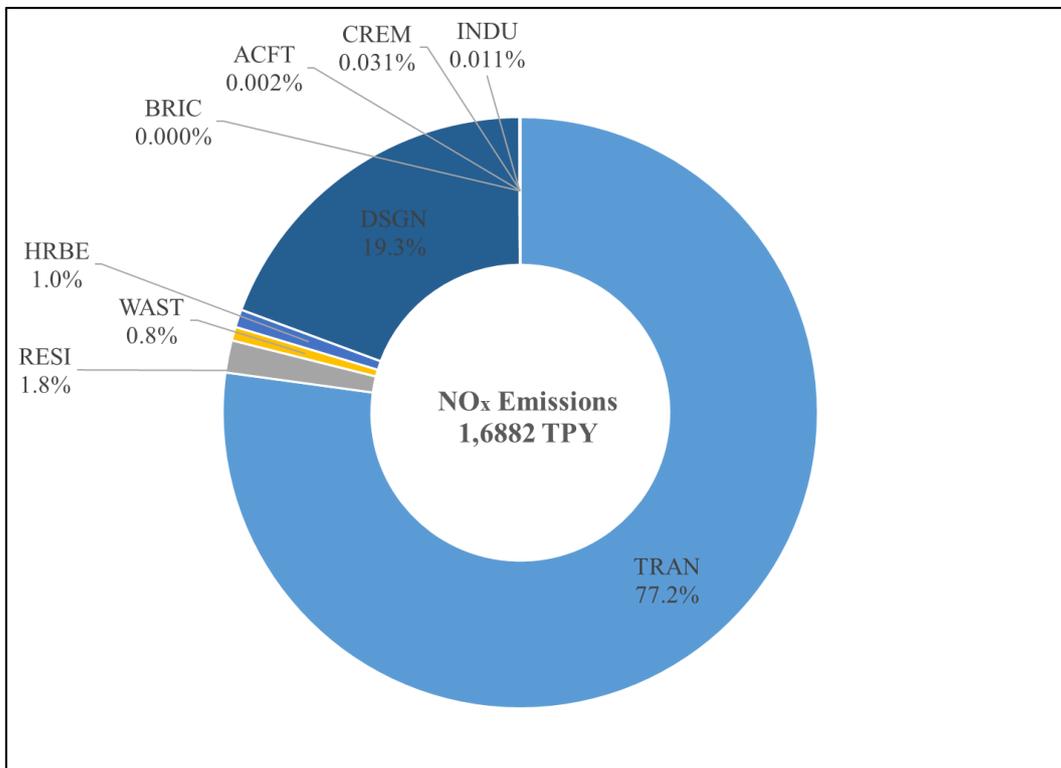


Figure 85 Sectoral contribution to annual NO<sub>x</sub> emissions in Bhubaneswar region

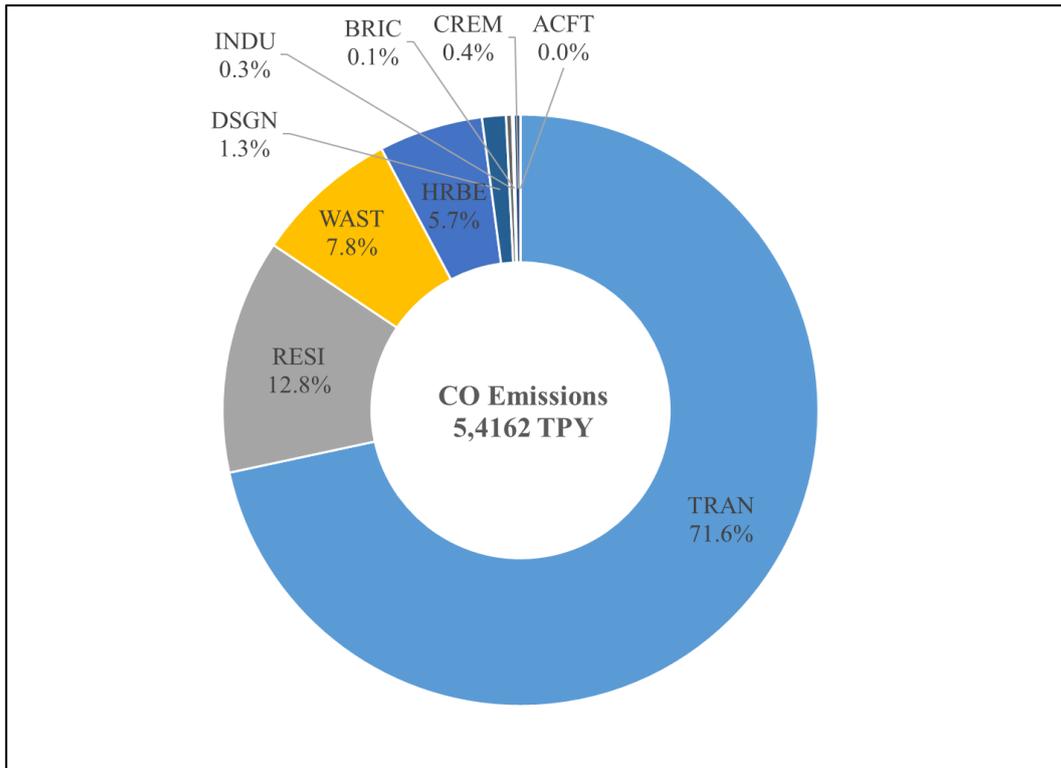


Figure 86 Sectoral contribution to annual CO emissions in Bhubaneswar region

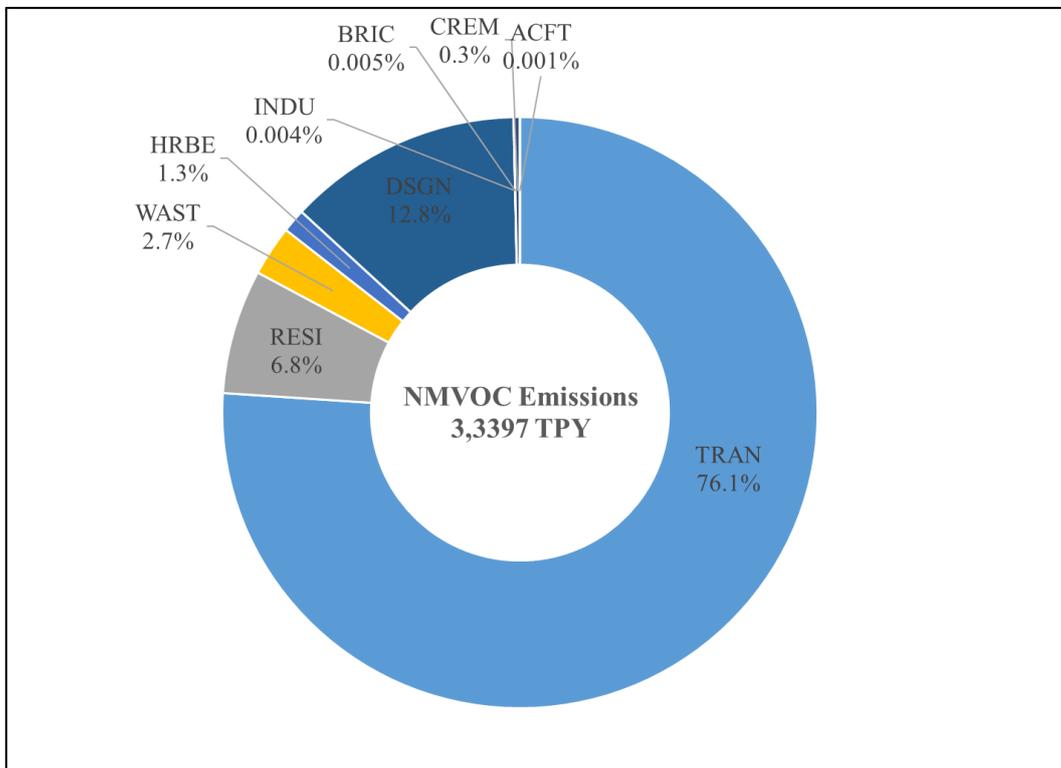


Figure 87 Sectoral contribution to annual NMVOC emissions in Bhubaneswar region

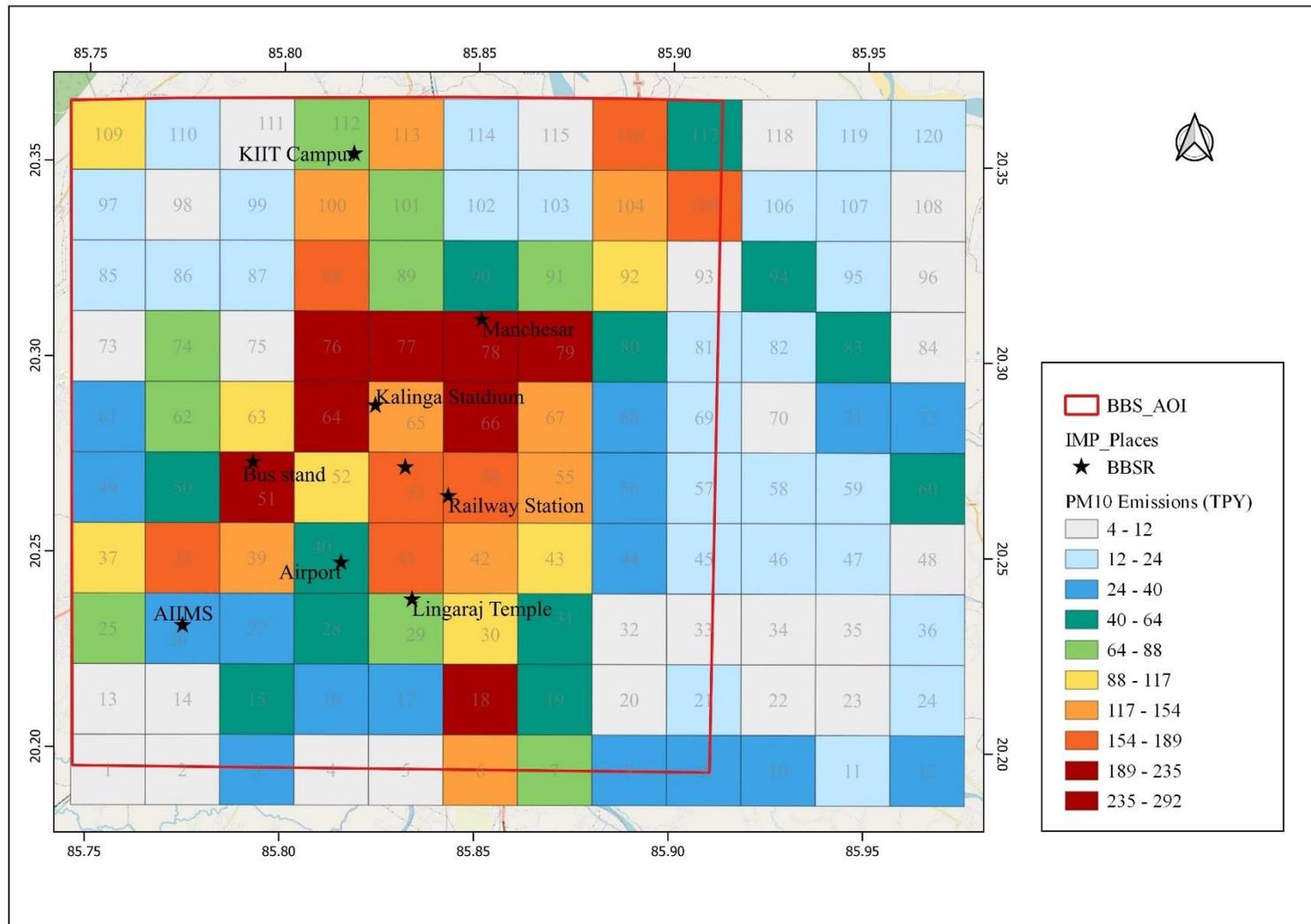


Figure 88: Spatial distribution of PM<sub>10</sub> emissions (tonnes per year) in Bhubaneswar region for year 2022

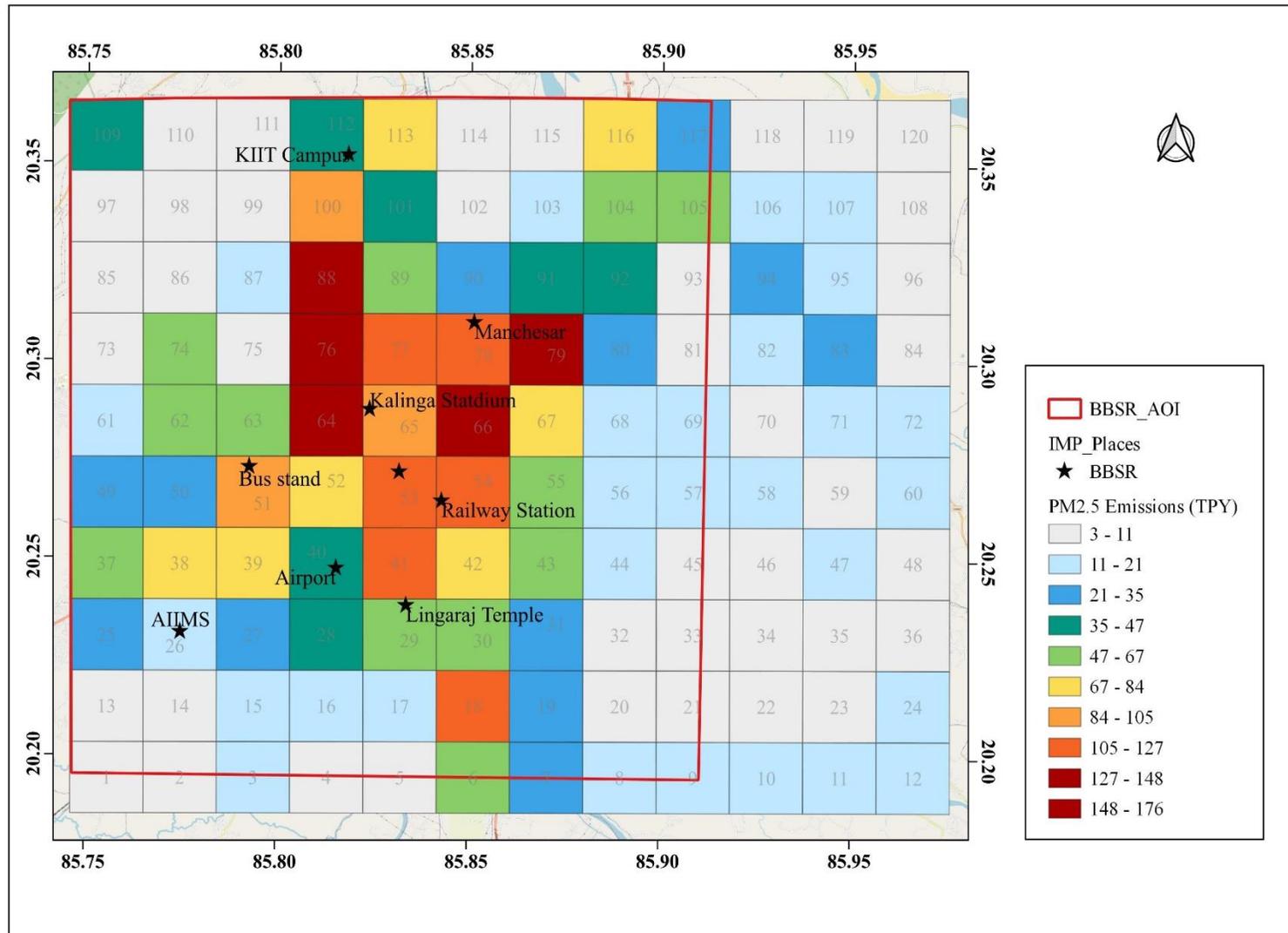


Figure 89: Spatial distribution of PM<sub>2.5</sub> emissions (tonnes per year) in Bhubaneswar region for year 2022

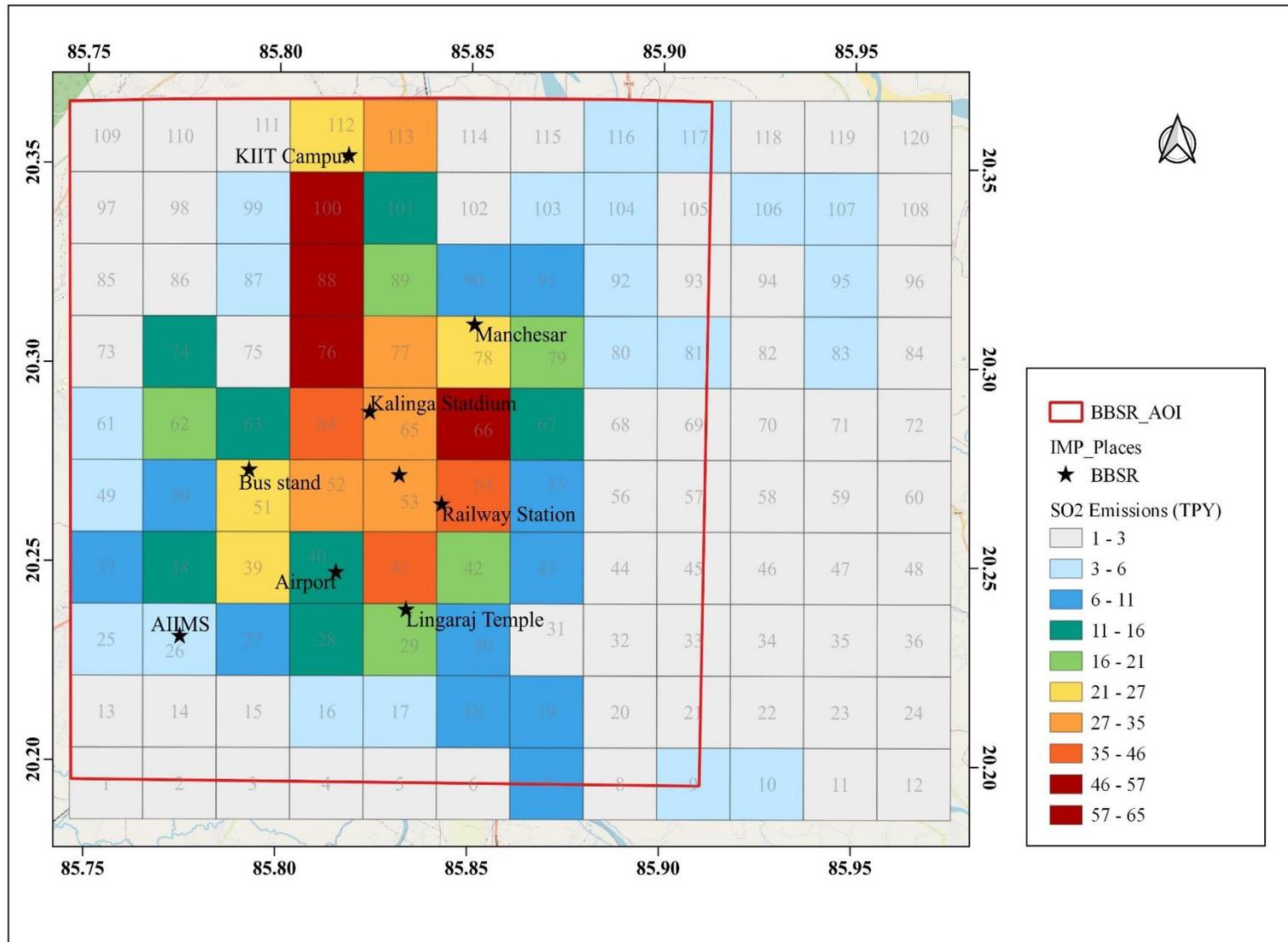


Figure 90 Spatial distribution of SO<sub>2</sub> emissions (tonnes per year) in Bhubaneswar region for year 2022

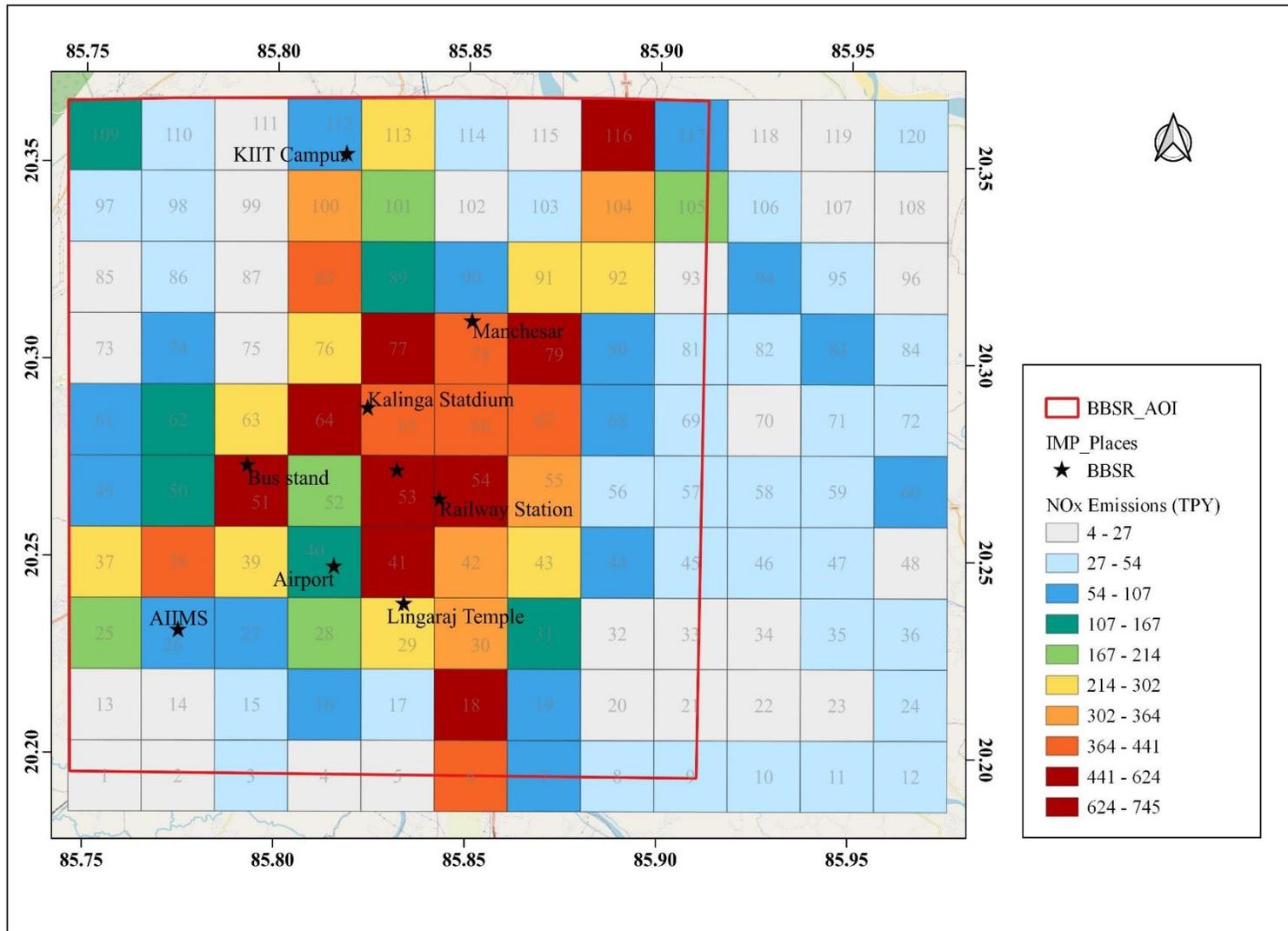


Figure 91 Spatial distribution of NO<sub>x</sub> emissions (tonnes per year) in Bhubaneswar region for year 2022

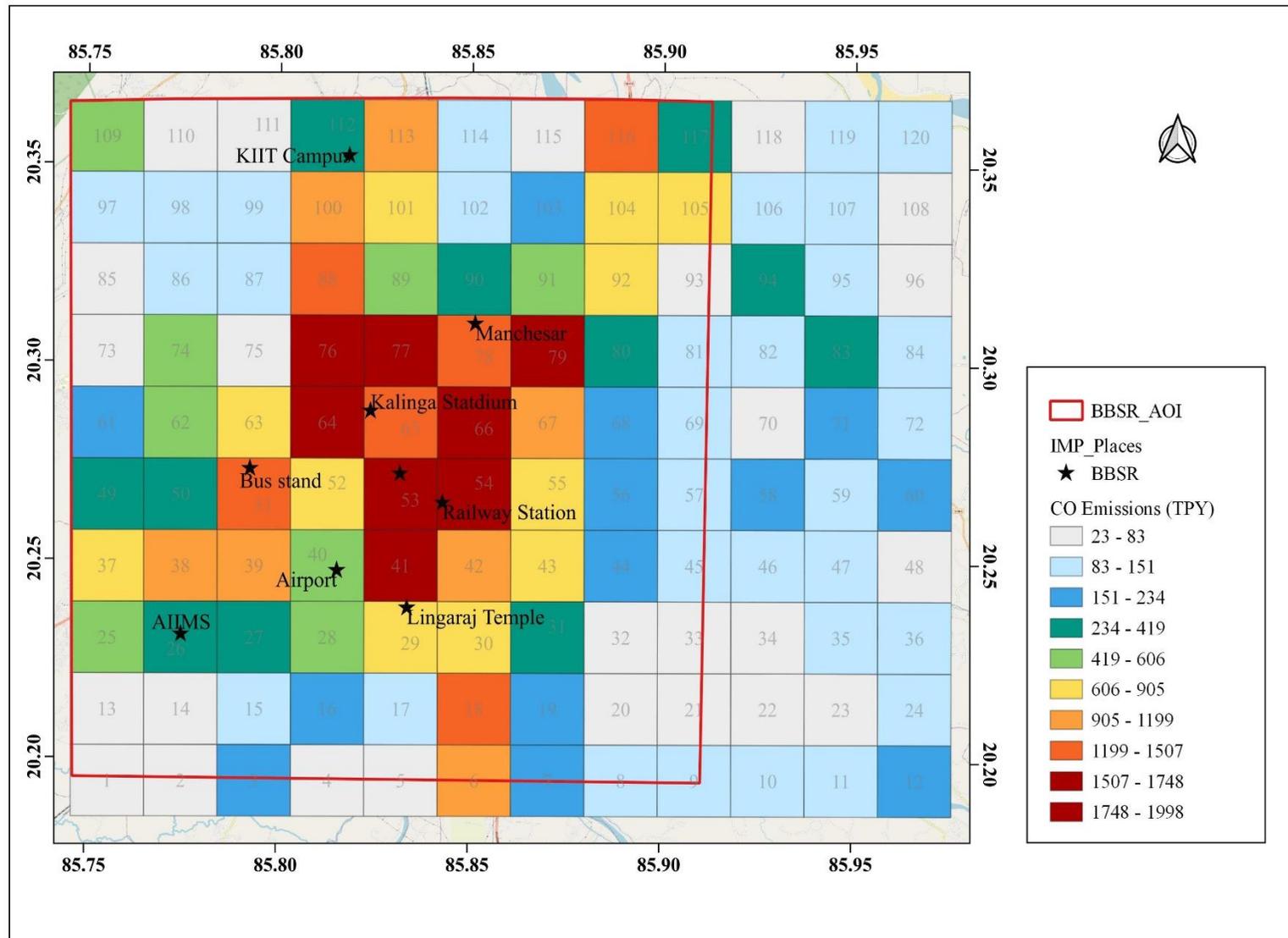
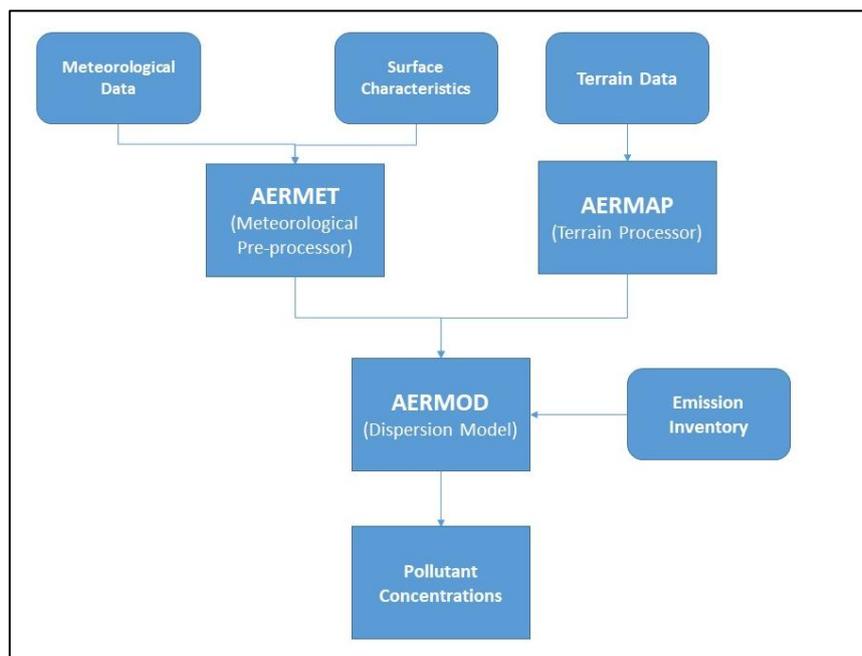


Figure 92 Spatial distribution of CO emissions (tonnes per year) in Bhubaneswar region for year 2022

## Chapter 4: Dispersion Modelling

### 4.1. Background

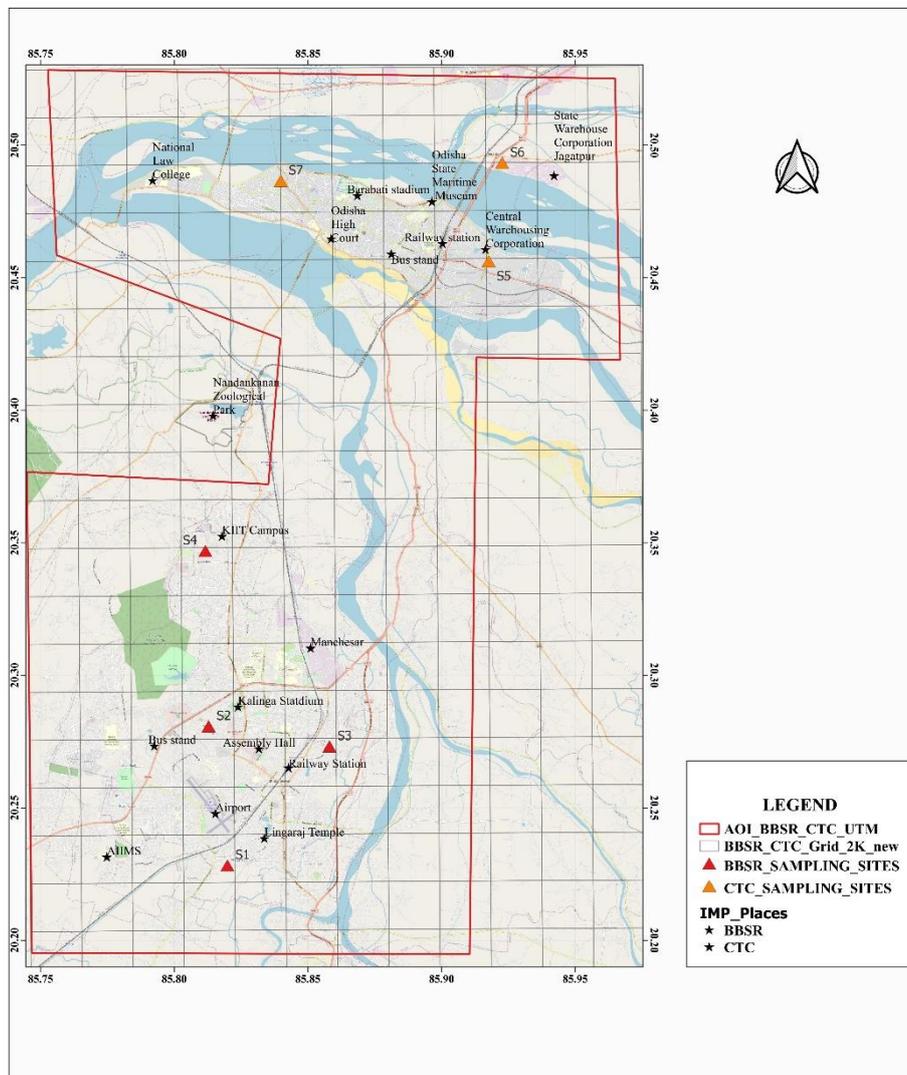
The dispersion modelling is a tool for predicting the spatio- temporal variations of air pollutants. In general, the dispersion models employ mathematical algorithms that considers various atmospheric processes such as dispersion, chemical, and physical processes and calculate approximate concentrations of air pollutants (Zou et al., 2010). AERMOD (AMS/EPA Regulatory **MO**Del), is a state-of-science dispersion modelling system for regulatory applications and is aimed at modelling short-range (up to 50 km) dispersion from a variety of source types including point, area, line and volume sources (Cimorelli et al., 2003; Holmes et al., 2006).



*Figure 93 Flow diagram of AERMOD Modelling System used in this study to simulate the air pollutant concentrations*

Fig. 93 shows the flow diagram of AERMOD modelling system. AERMOD is a steady-state gaussian plume model and consists of a dispersion model i.e. AERMOD and two pre-processors (AERMET and AERMAP). The major purpose of meteorological pre-processor i.e. AERMET, is to calculate boundary layer parameters for use by AERMOD. Surface characteristics in the form of albedo, surface roughness, and Bowen ratio, plus standard meteorological observations (wind speed, wind direction, temperature, and cloud cover), are

input to AERMET. AERMET then calculates the PBL parameters: friction velocity ( $u^*$ ), Monin-Obukhov length ( $L$ ), convective velocity scale ( $w^*$ ), temperature scale ( $\theta^*$ ), mixing height ( $z_i$ ), and surface heat flux ( $H$ ). The terrain pre-processor i.e. AERMAP uses gridded terrain data to calculate a representative terrain-influence height, also referred to as the terrain height scale. The terrain height scale, which is uniquely defined for each receptor location, is used to calculate the dividing streamline height. The gridded data needed by AERMAP is selected from Digital Elevation Model (DEM) data. AERMAP is also used to create receptor grids. The elevation for each specified receptor is automatically assigned through AERMAP. For each receptor, AERMAP passes the following information to AERMOD: the receptor's location, its height above mean sea level, and the receptor specific terrain height scale.



*Figure 94 Map showing dispersion modelling domain i.e. Bhubaneswar and Cuttack  
(Combined) region and surrounding areas*

In this study, the AERMOD model is configured to consider the local meteorology, emissions and terrain information to simulate the air pollutant concentrations at specified receptors in the study domain (Figure 94). Due to proximity and importance of regional sources, Bhubaneswar and Cuttack regions are modelled together in AERMOD System.

## **4.2. Meteorological Data**

AERMOD modelling system requires two types of meteorological datasets i.e. surface meteorological data and upper air soundings. This data is first pre-processed by the meteorological processor i.e. AERMET. The main purpose of AERMET is to calculate boundary layer parameters for use by AERMOD.

This study primarily uses ERA5 reanalysis meteorological data. ERA5 is the fifth generation ECMWF reanalysis for the global climate and weather for the past 4 to 7 decades. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics. Data has been re-gridded to a regular lat-lon grid of 0.25 degrees for the reanalysis and 0.5 degrees for the uncertainty estimate. Table 18 provides summary of ERA5 reanalysis dataset.

The surface level meteorological data over the Bhubaneswar region is extracted from ERA-5 dataset. The minimum meteorological input data requirements for input to AERMOD are: Wind speed and direction, Ambient temperature, Opaque sky cover and/or total sky cover (EPA, 2004). The hourly meteorological data of specified weather parameters obtained from ERA-5 data for year 2022 is converted to Solar and Meteorological Surface Observation Network (SAMSON) format using customized python scripts following data quality assurance.

As discussed previously, in addition to surface meteorological data, AERMET also requires the twice daily upper air soundings i.e. 00Z and 12Z, for calculation of micro-meteorological parameters over the study domain. The pressure level data over Bhubaneswar from ERA-5 database and is converted into Forecast Systems Laboratory (FSL) radiosonde format using Python and Fortran scripts.

Table 18 Details of ERA5 meteorological dataset used in this study

Data type	Gridded
Projection	Regular latitude-longitude grid
Horizontal coverage	Global
Horizontal resolution	Reanalysis: 0.25° x 0.25° (atmosphere), 0.5° x 0.5° (ocean waves) Mean, spread and members: 0.5° x 0.5° (atmosphere), 1° x 1° (ocean waves)
Temporal coverage	1979 to present
Temporal resolution	Hourly
Vertical coverage	1000 hPa to 1 hPa
Vertical resolution	37 pressure levels

Additionally, the surface meteorological observations at Bhubaneswar are obtained from the observatory located at Biju Patnaik International Airport (Refer Figure 94). This data is available from Integrated Surface Database (ISD) maintained by National Oceanic and Atmospheric Administration (NOAA). The meteorological parameters including: wind speed and direction, ambient temperature and cloud cover are ingested into AERMET files via ONSITE pathway. The sub-hourly meteorological observations of specified weather parameters obtained from ISD data for year 2022 are processed using customized python scripts following data quality assurance.

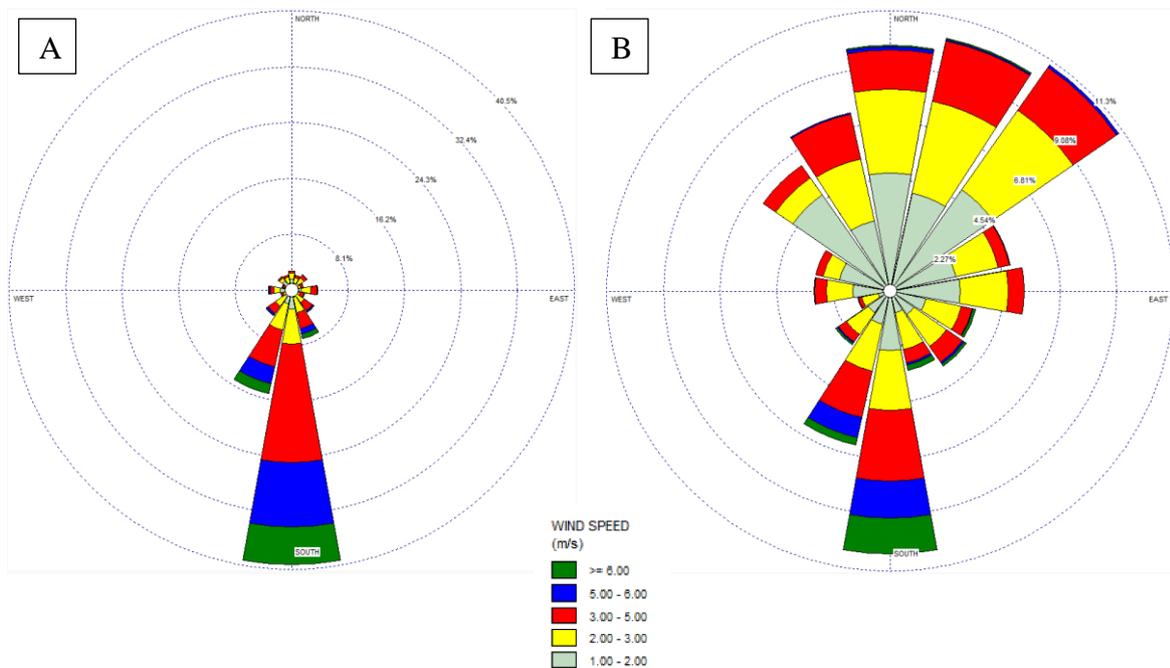


Figure 95 Windrose diagrams showing the wind speed and direction frequency distribution over Bhubaneswar region during summer (A) and winter (B) seasons of year 2022

Fig. 95 shows the wind speed and direction frequency distribution over Bhubaneswar region during summer (A) and winter (B) seasons of year 2022. The predominant wind directions during the summer season over Bhubaneswar region are observed to be from south (S, >40%); followed by south of south west (SSW, ~16%). The calm winds i.e. < 1 m/s, are observed for 2.47% of time, during summer season.

In the winter season, the winds are observed to blow from north-east and south quadrant, with maximum from north east (NE, > 11%), followed by north of north east (NNE, >10%), south (S, >10%), and north (N, >10%) directions. Calm winds i.e. < 1 m/s, constituted a significant portion i.e. 6.35%, during the winter season.

### **4.3. Terrain Data**

The terrain data is required by AERMOD, to calculate a representative terrain-influence height, which in turn is used to calculate the dividing streamline height. A pre-processor program, AERMAP, processes the terrain data in conjunction with a layout of receptors and sources to be used in AERMOD simulations. AERMAP processor needs standardized computer files of terrain data. For Indian region, the terrain data available from NASA's Shuttle Radar Topography Mission (SRTM) global product having 1 arc second (~30 meter) spatial resolution. The SRTM DEM data over Bhubaneswar region was downloaded and processed using AERMAP processor.

Fig. 96 shows the contour map showing terrain elevations over Bhubaneswar-Cuttack (Combined) modelling domain, extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m). The terrain elevations are observed to vary from a minimum of ~11 m (above MSL) towards southern part to a maximum of ~82 m (above MSL) towards western part of the modelling domain.

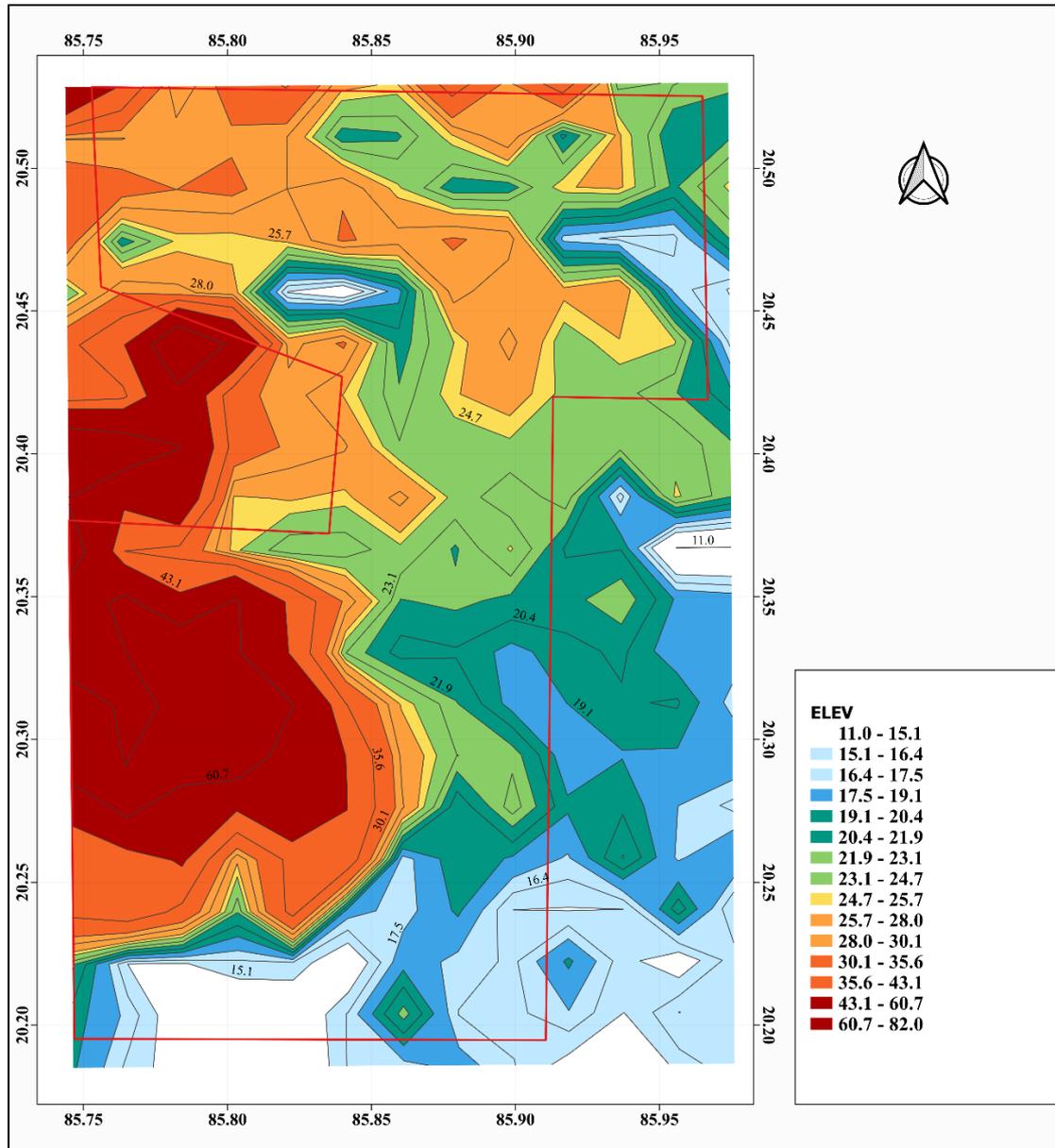


Figure 96 Contour map showing terrain elevations extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m)

## 4.4. Source Configurations

AERMOD can simulate emissions originating from variety of source types including: point, area, line, and volume sources. The emissions from different sectors are modelled as area sources, except the industries and thermal powerplants, crematoria, industrial fugitive dust and brick kilns. The stack emissions from industries, thermal powerplants, crematoria, and FCBTK brick kilns are modelled as point sources. Industrial fugitive dust sources are modelled as area polygon sources while clamp type brick kilns are modelled as volume sources.

## 4.5. Receptor Configurations

Receptor information is required by AERMOD to calculate the pollutant concentrations. Two types of receptors i.e. gridded and discrete, are used in this study to simulate the concentrations. The gridded receptors are placed at the vertex of each grid cell used in the emission inventorization, forming a network of 260 gridded receptors. Additionally, seven discrete receptors are also configured, to represent the locations for ARAI sampling sites. The height of each receptor is set to 1.5 m above ground level i.e. mean breathing level for humans. Figure 97 shows map of the modelling domain overlaid by gridded and discrete receptors configured in this study.

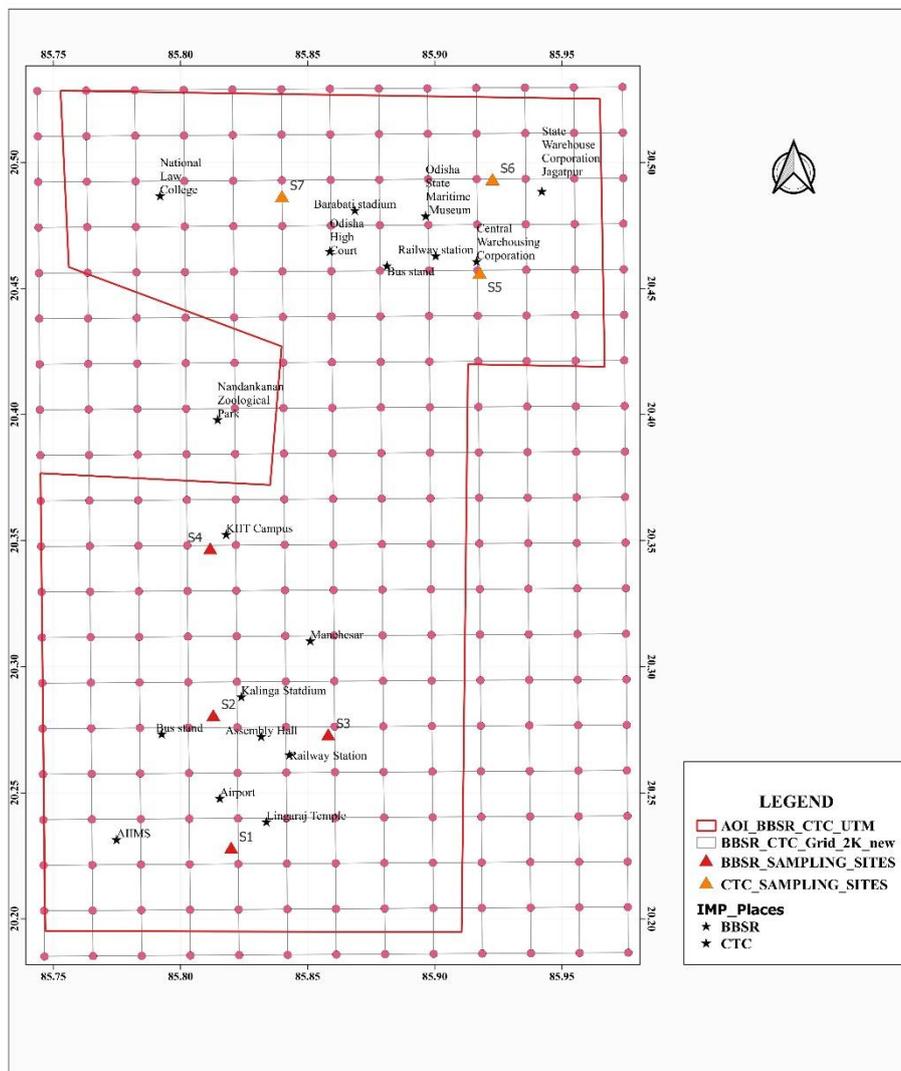


Figure 97 Map showing modelling domain overlaid by gridded and discrete receptors configured in this study.

Table 19 summarizes the details of dispersion model, source and receptor configurations, meteorology and geophysical data used for dispersion modelling simulations.

*Table 19 Summary of AERMOD dispersion modelling setup used in this study*

S. No.	Description	Symbol	Details
1.	Length of modelling domain in X-direction	X	24 km
2.	Length of modelling domain in Y-direction	Y	38 km
3.	X-direction receptor grid resolution	$\Delta X$	2000 m
4.	Y-direction receptor grid resolution	$\Delta Y$	2000 m
5.	Receptor height	$H_R$	1.5 m
6.	Total number of gridded receptors	$N_{GRD}$	260
7.	Total number of discrete receptors	$N_{DISC}$	7
8.	Source configuration in AERMOD	--	<ul style="list-style-type: none"> <li>• Industries, TPP, FCBTK, Crematoria: Point source</li> <li>• Clamp Brick kilns: Volume source</li> <li>• Industrial fugitive dust: Area polygon sources</li> <li>• All other sectors: Area sources having L=2000 m and W= 2000 m</li> </ul>
9.	Meteorology: Surface data	--	ERA5 fifth generation ECMWF reanalysis: <ul style="list-style-type: none"> <li>• Dry bulb temperature</li> <li>• Wet bulb temperature</li> <li>• Cloud cover</li> <li>• Wind speed at 10 m</li> <li>• Wind direction at 10 m</li> </ul> Onsite Meteorological data: <ul style="list-style-type: none"> <li>• Dry bulb temperature</li> <li>• Wet bulb temperature</li> <li>• Cloud cover</li> <li>• Wind speed</li> <li>• Wind direction</li> </ul>
10.	Meteorology: Upper air soundings	--	ERA5 fifth generation ECMWF reanalysis <ul style="list-style-type: none"> <li>• Dry bulb temperature</li> <li>• Wet bulb temperature</li> <li>• Wind speed</li> <li>• Wind direction</li> </ul>
11.	Terrain data	--	NASA's Shuttle Radar Topography Mission (SRTM) global product having 1 arc second (~30 meter) spatial resolution

## **4.6. Background Concentrations**

The background pollutant concentrations play an important role in dispersion model validation. Continuous air quality monitoring stations were not operational during baseline year 2022, hence NAMP observations were used to derive the background concentrations. NAMP monitoring stations are operated manually and the background concentrations are derived using annual average concentrations reported at NAMP stations with suitable assumptions.

Based on literature review, previous studies in the region, results of receptor modelling in this study, and expert judgement, the background pollutant concentrations are reported to contribute between 15 and 30% (Urban Emissions Info, 2024). A series of sensitivity AERMOD simulations were conducted with varying background concentrations to cover the previously reported range of 15% to 30%. The best model results were obtained when the background concentrations were ~20%, hence this value is used to get the monthly background concentrations. The derived background concentration is added to the modelled concentrations estimated by AERMOD to get total concentration of pollutant under consideration.

## **4.7. Dispersion Model Validation**

Due to lack of CAAQM measurements in Bhubaneswar region, the AERMOD simulated concentrations of pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, and NO<sub>2</sub>, are compared against monthly mean of reported observations at NAMP stations in Bhubaneswar-Cuttack regions. The Pearson correlation coefficient (R) is found to be greater than 0.7 for PM<sub>10</sub> and PM<sub>2.5</sub>. Overall, the AERMOD model is found to simulate the monthly average concentrations of the pollutants with a good accuracy compared to NAMP observations.

## **4.8. Spatial Distribution of Modelled Pollutants**

Fig. 98 - 102 shows the spatial distribution of modelled pollutant annual mean concentrations of PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>2</sub> and CO for year 2021, respectively. The spatial distribution of modelled pollutant concentrations in the study domain, is generally governed by emissions, terrain, land-use and meteorological factors. The highest estimated concentrations of particulate matter i.e. PM<sub>10</sub> and PM<sub>2.5</sub> are observed towards central parts of Bhubaneswar and Cuttack cities as well as southern parts of the study domain. These highest concentrations can be attributed to the air polluting sources such exhaust emissions, road dust

emissions due to vehicular movement, fuel combustion in households and commercial facilities. The lowest estimated pollutant concentrations on the peripheral part of the study domain i.e. north-western (NW) and south-eastern (SE), could be attributed to no and or less air polluting activities, emissions and effective diffusion, dispersion and removal of pollutants to some extent (Han et al., 2020).

The spatial distribution of gaseous pollutants such as SO<sub>2</sub> (Refer Fig. 100) is mainly governed by the use of solid fuels such as coal in residential sector and hotels, restaurants and bakeries. The NO<sub>2</sub> and CO concentrations are found to be distributed across the domain. The vehicular exhaust emissions, industries and thermal powerplants in the peripheral parts are main sources of NO<sub>x</sub>. In addition to industries and traffic, incomplete combustion of solid fuels such as coal and wood for domestic and commercial purposes in the region, explains the persistent CO concentrations.

Due to prevailing wind speeds and direction, the pollutant concentrations are tended to spread to the north (N) and south-eastern (SE) part of the domain during summer and winter seasons, respectively.

The estimated concentrations show distinct seasonal pattern, being higher in winter and comparatively lower in summer, except a few locations very close to fugitive dust sources. This trend in ambient concentrations is mainly due to prevailing stable meteorological conditions with lower ambient temperatures, higher relative humidity and lower mixing heights, which hinders the dispersion of pollutants. This implies that, the seasonal emissions and meteorology are adequately explained by the model.

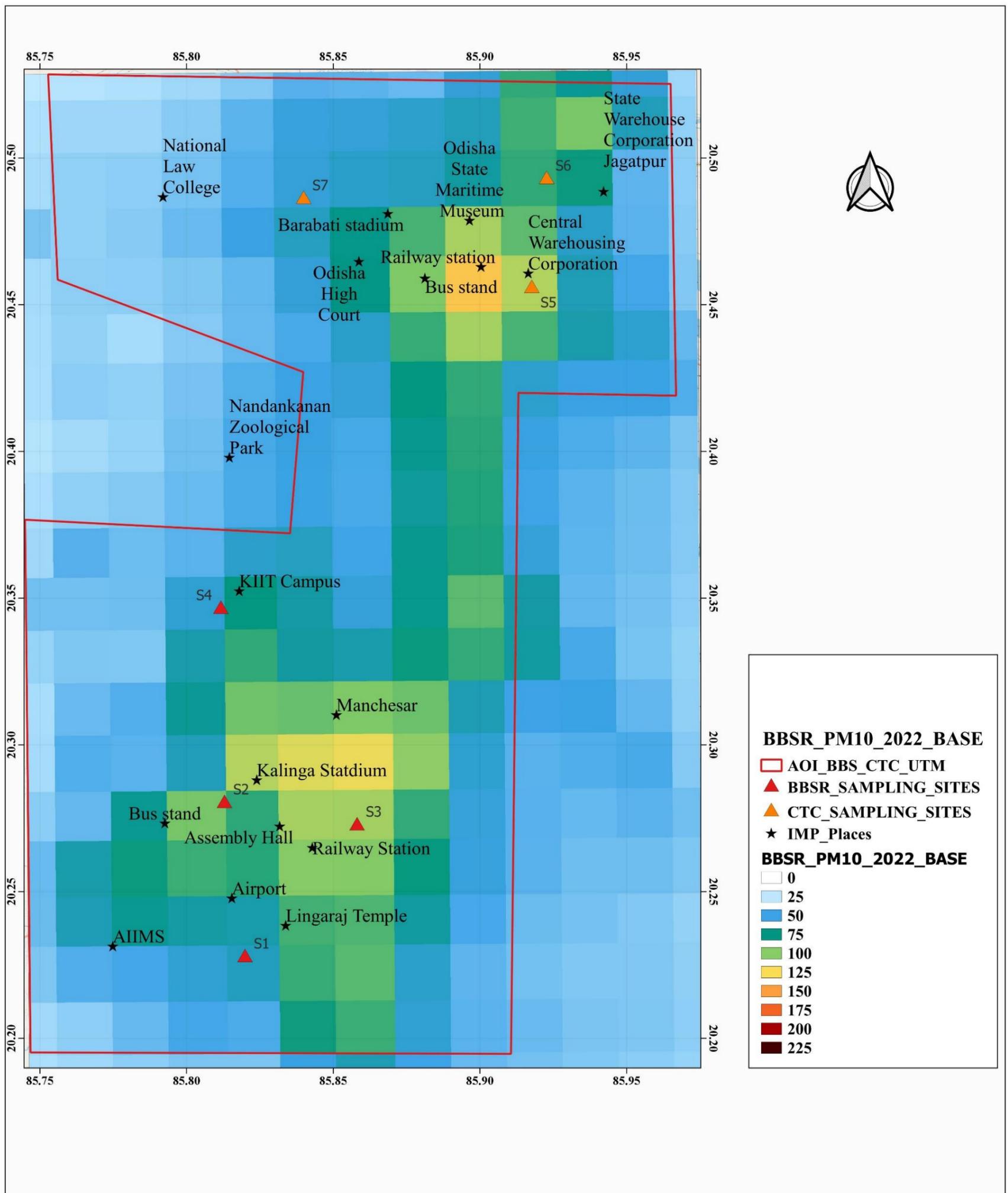


FIGURE 98 MAP SHOWING SPATIAL DISTRIBUTION OF ANNUAL MEAN  $PM_{10}$  CONCENTRATIONS ( $\mu G/M^3$ ) OVER BHUBANESWAR-CUTTACK REGION FOR YEAR 2022

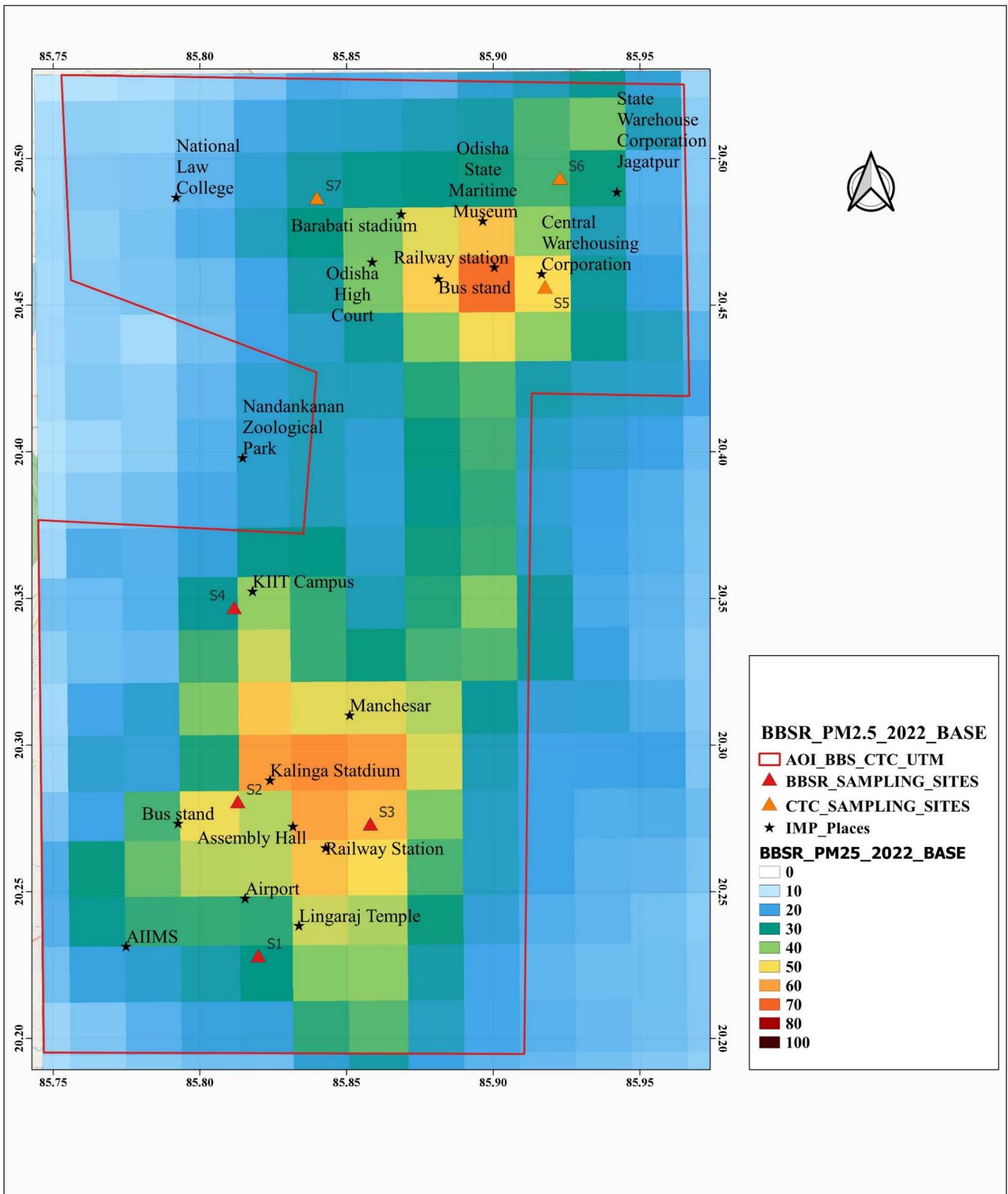


FIGURE 99 MAP SHOWING SPATIAL DISTRIBUTION OF ANNUAL MEAN  $PM_{2.5}$  CONCENTRATIONS ( $\mu g/m^3$ ) OVER BHUBANESWAR-CUTTACK REGION FOR YEAR 2022

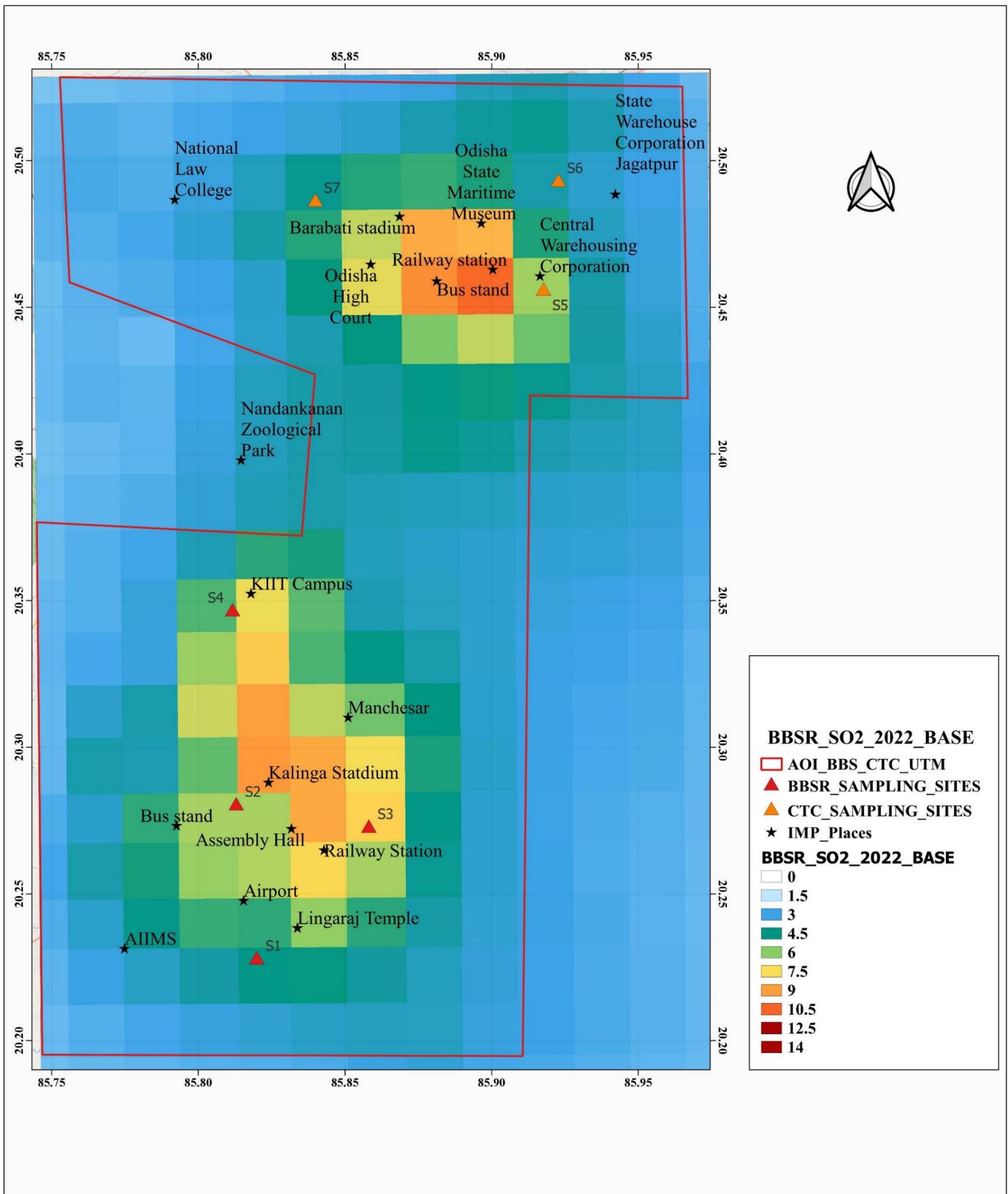


FIGURE 100 MAP SHOWING SPATIAL DISTRIBUTION OF ANNUAL MEAN SO<sub>2</sub> CONCENTRATIONS (µG/M<sup>3</sup>) OVER BHUBANESWAR-CUTTACK REGION FOR YEAR 2022

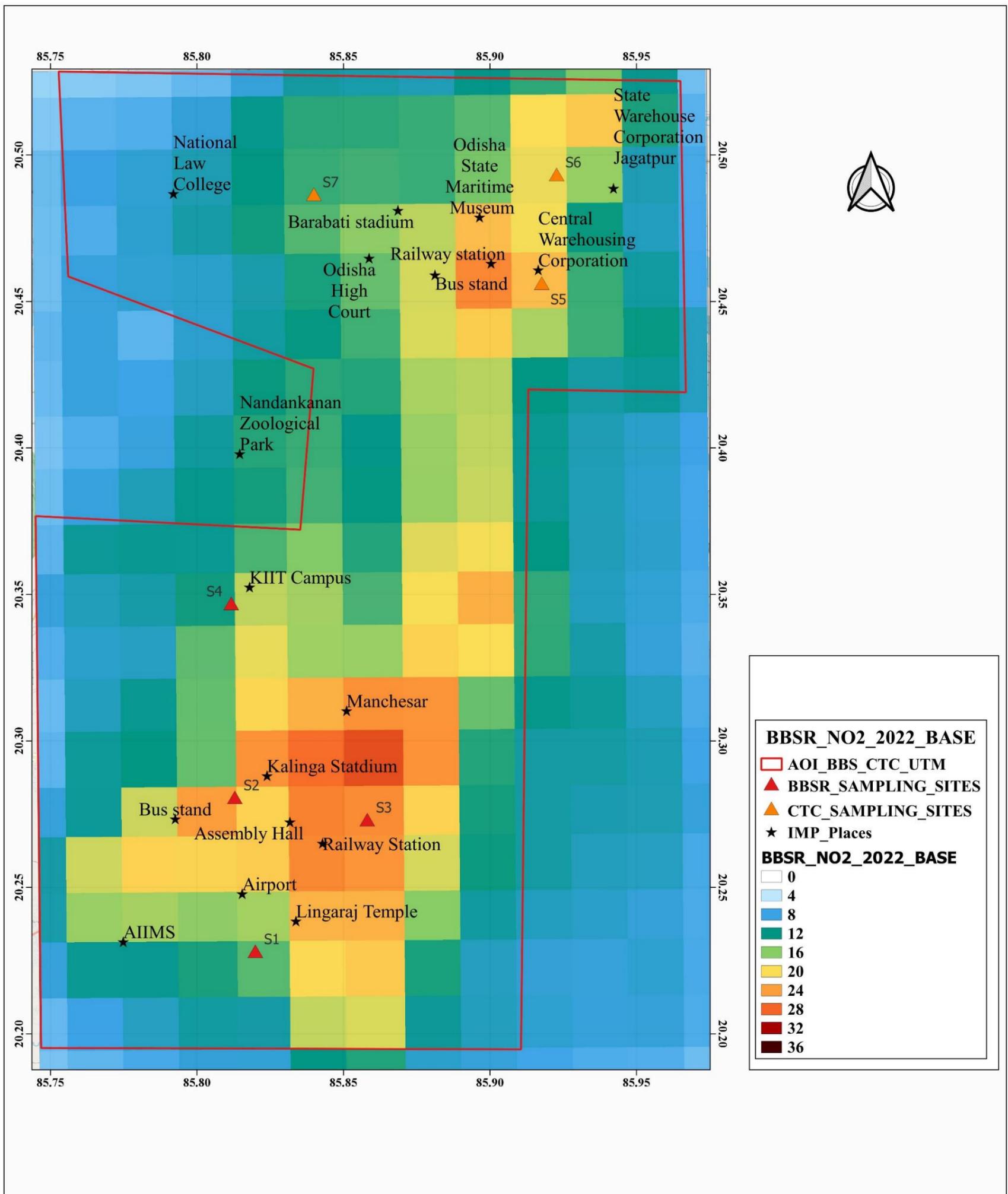


FIGURE 101 MAP SHOWING SPATIAL DISTRIBUTION OF ANNUAL MEAN NO<sub>2</sub> CONCENTRATIONS (µG/M<sup>3</sup>) OVER BHUBANESWAR-CUTTACK REGION FOR YEAR 2022

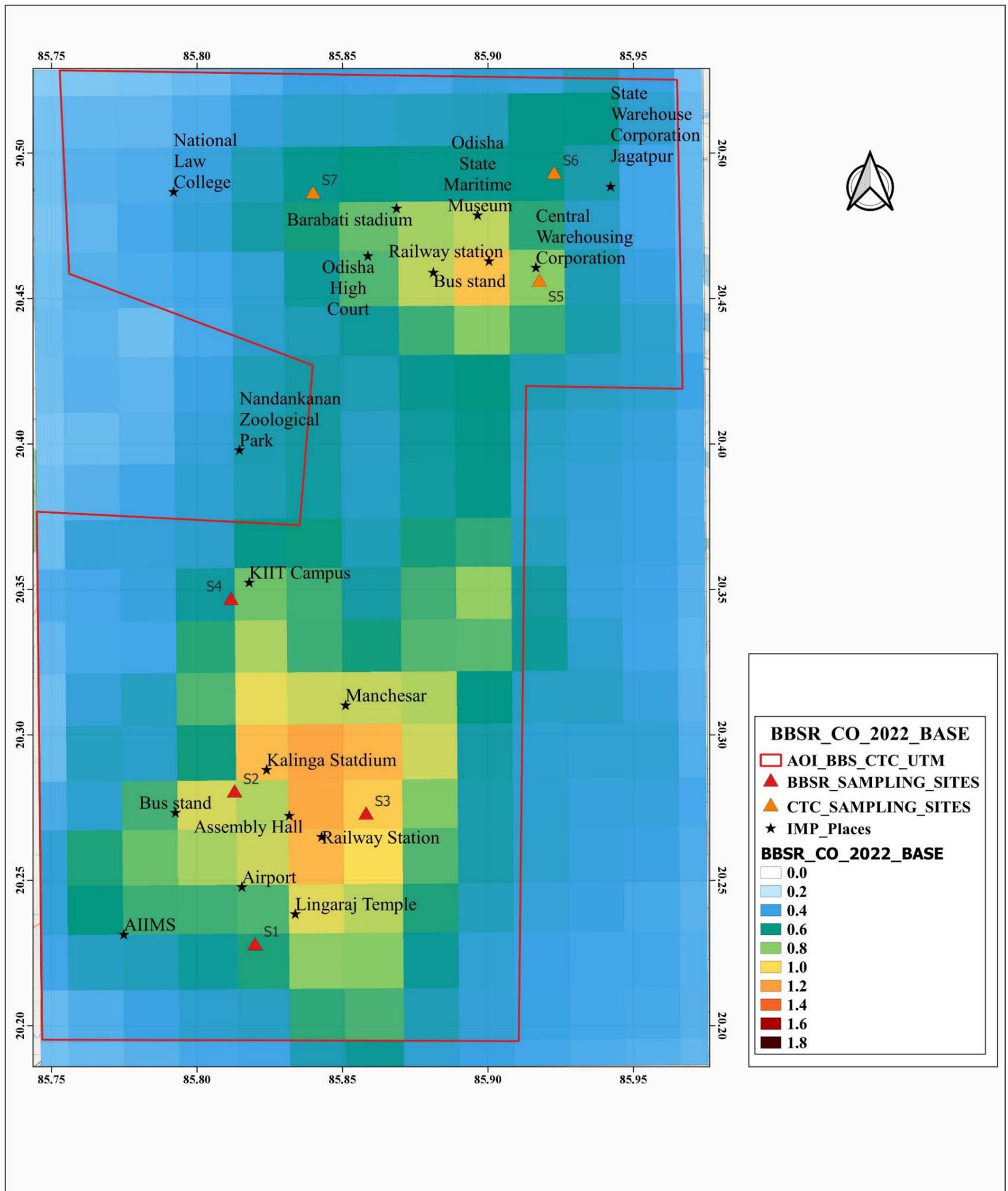


FIGURE 102 MAP SHOWING SPATIAL DISTRIBUTION OF ANNUAL MEAN CO CONCENTRATIONS (MG/M3) OVER BHUBANESWAR-CUTTACK REGION FOR YEAR 2022

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## Chapter 5: Future Projections

### 5.1. Future Projections of Emissions and Air Quality Benefits

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 2022. Four hypothetical emission scenarios viz. i) No further control (NFC), ii) Business-as-usual (BAU), iii) Scenario – I (SC-I) and iv) Scenario – II (SC-II); are developed for Bhubaneswar region to include various existing and planned control interventions in each sector. These scenarios can be defined as given below:

- i) **No further control (NFC):** No further control (NFC) scenario assume that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 but the control measures would be similar to present/current levels in baseline year 2022.

For example, Bhubaneswar metro rail is expected to be operational by 2028 but it is currently not operational. NFC scenario quantifies emissions assuming the activities will increase as per the sector specific growth rate and metro train won't be operational in future years.

- ii) **Business-as-usual (BAU):** Business-as-usual (BAU) scenarios consider that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032. The control actions that are already planned and are expected to be complete or operational by respective projection years i.e. 2027 and 2032 are considered while designing the BAU scenarios. The sector-wise details on level of penetration and/or implementation are provided in sub-subsequent sections of this chapter.

For example, Bhubaneswar metro rail is expected to be operational by 2028. The emission benefits from this action are considered in BAU projections of year 2032, only.

- iii) **Scenario – I (SC-I):** Scenario – I (SC-I) consider that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 while the planned control measures would be implemented more aggressively compared to BAU scenarios. The sector-wise details on level of penetration and/or implementation are provided in sub-subsequent sections of this chapter.
- iv) **Scenario – II (SC-II):** Scenario – II (SC-II) consider that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 while the

planned control measures would be implemented to the highest aggressive levels, possible. The sector-wise details on level of penetration and/or implementation are provided in sub-subsequent sections of this chapter.

These scenarios consider changes in technology and fuels which mainly include: faster EV adoption, implementation of BS-VI, increase in penetration of natural gas-based vehicles, roll-out of ethanol blended gasoline fuel (E20), reduction in silt loading on road surfaces, operational mass transit system (MRTS), improvement in NMT & public transport, usage of clean fuel for cooking, improved waste collection efficiency, continuous supply of grid electricity, adoption of Zig-zag type brick kilns and various other control measures. The four emission scenarios investigated in the study can be further categorized as mid-term (2027) and long term (2032). The assumptions and considerations in each scenario are described in this section.

## **5.2. Transport Sector**

In order to estimate vehicular emissions for four emission scenarios, change in fuel-wise vehicle penetration fractions for each category of vehicles, change in emission factors due to new technology and fuels, and reduction in vehicle kilometres travelled is considered for 2027 and 2032. This section explains the control measures used in the present study and the vehicle category-wise considerations for each scenario are provided in Annexure-H.

### **5.2.1. Increased penetration of Bharat Stage (BS) – VI vehicles**

In April 2020, the Bharat Stage (BS) - VI standards were introduced and all new vehicles manufactured have to comply with BS-VI. BS-VI vehicles are significantly cleaner than the BS IV counterparts. For example, particulate matter (PM) limit for different segments of diesel cars will be 82 to 93 per cent lower while for trucks and buses it will be 50-67 per cent lower than BS IV level. Similarly, Nitrogen oxide (NO<sub>x</sub>) emissions limit will be 68 per cent lower compared to BS-IV norms. This effect is included in the present study considering increased penetration levels of these vehicles in future vehicle fleet of Bhubaneswar region and reduced emissions per unit distance.

### **5.2.2. Roll-out of Ethanol blended Gasoline (E20) fuel**

On the occasion of World Environment Day, 5 June 2021, the government of India released the Roadmap for Ethanol Blending in India. This roadmap is aimed at reducing the

country's oil import bill and carbon dioxide pollution. The roadmap proposed some important milestones including: i) raising Pan-India ethanol production capacity from the current 700 to 1500 crore litres; ii) Phased rollout of E10 fuel by April 2022; iii) Phased rollout of E20 from April 2023; its availability by April 2025; iv) Rollout of E20 material-compliant and E10 engine-tuned vehicles from April 2023; and v) Production of E20-tuned engine vehicles from April 2025 (NITI Aayog and MoPNG, 2021).

The impact of 20 per cent ethanol blending in gasoline i.e. E20 fuelled vehicles in Bhubaneswar region, is included in the analysis in years 2027 and 2032. In modelling, the impact of E20 roll-out, it is considered that all vehicle categories which currently use gasoline, will be using E20 as fuel in 2030. It is also assumed that the vehicle fleet produced between the period from 2027 to 2032 will have an E20-tuned engine, which will in turn lead to change in emissions per unit distance. Although vehicles produced before 2025 will be using E20 as fuel in the subsequent years, yet it is assumed that there will not be a significant change in the emission factors for these vehicles.

### **5.2.3. Increased Penetration of Electric Vehicles (EV)**

The conventional internal combustion engine (ICE) vehicles are one of the major contributors to city level air pollution and electric vehicles (EVs) are emerging as a promising alternative that could help in mitigating air pollution in urban centres (GIZ, 2021). The Government of India (GoI) has introduced several initiatives in EV sector with an aim to improve energy security, curb local air pollution, and curtail GHG emissions from the transport sector (CEEW, 2020). For example, India has set a goal of 30 per cent penetration of EV in new sales by 2030 (GIZ, 2021). Additionally, several state governments have also set their own targets to increase the electric vehicle penetration in near future by incentivising the EV purchases.

Considering the government policies and initiatives, EV penetration is likely to improve substantially in Bhubaneswar region as well, which will in turn lead to significant reduction in vehicular exhaust emissions. The effect of increased EV penetration in Bhubaneswar region is included by referring to policies at national, state and city-level and the expected EV penetration.

#### **5.2.4. Non-Motorised Transport (NMT) Share**

Non-motorised transport (NMT) includes mainly walking, cycling and cycle rickshaws. NMT plays an important role in Indian cities as a last mile connector providing access to mass transit systems (Kumar et al., 2015). Several government policies and initiatives including but not limited to, National Urban Transport Policy (NUTP), National Mission for Sustainable Habitat (NMSH), and Ministry of Urban Development (MoUD) Service level benchmarks are aiming to adopt NMT as a key component of city's integrated urban transport system (Kumar et al., 2015).

As NMT is may play a vital role in Bhubaneswar region urban transportation system in the years to come, we have evaluated the impact of increasing NMT share on vehicle kilometres travelled and subsequent emission reductions. It is assumed that increasing NMT share in future years would reduce VKT by two wheelers, cars and buses. Table 20 presents summary of assumed reduction percentages in vehicle kilometres travelled (VKT) in three scenarios for years 2027 and 2032, respectively, due to promotion of NMT in Bhubaneswar region.

Table 20 Percentage VKT reduction of selected vehicle categories during future scenarios

Year	BAU	SC-I	SC-II
2027	0.25%	0.5%	1.0%
2032	0.5%	1.0%	2.0%

### 5.2.5. Mass Rapid Transit System (MRTS)

Bhubaneswar Metro is a metro rail based rapid transit system under construction to serve the city of Bhubaneswar. The phase-I of the proposed system comprise of one line with a total length of ~26 km. This line is proposed to operate from Bhubaneswar Airport to Trisulia Square. The phase I of Bhubaneswar MRTS is likely to be operational from 2028.

Figure 103 shows the map of two proposed MRTS line and their zone of influence considered in future scenario analysis. The details of daily ridership, and average trip length of Bhubaneswar MRTS are used in this study for assessment of emissions in future scenario years. MRTS implementation would subsequently reduce the vehicular kilometres travelled in the zone of influence (ZIF), as people will shift from their current mode of transport to MRTS. In the present study, the methodology for estimation of emissions reduced due to shifting of on-road vehicles after the introduction of metro rail system has been adopted from Sharma et al. (2010; 2014).

### 5.2.6. Public Transport Improvement (PTI)

Public transportation systems play a vital role in reducing traffic and environmental pollution. Many researchers world-wide have demonstrated the potential emission reductions from a shift towards public transport and zero emission buses (Al-Kheder, 2021; Carroll et al., 2019; Bakker and Konings, 2018). The VKT shift approach used by Sharma et al. (2010 and 2014) is adopted to calculate the VKT shifted to buses and emission reductions achieved. The details of assumptions are provided in Annexure-H.

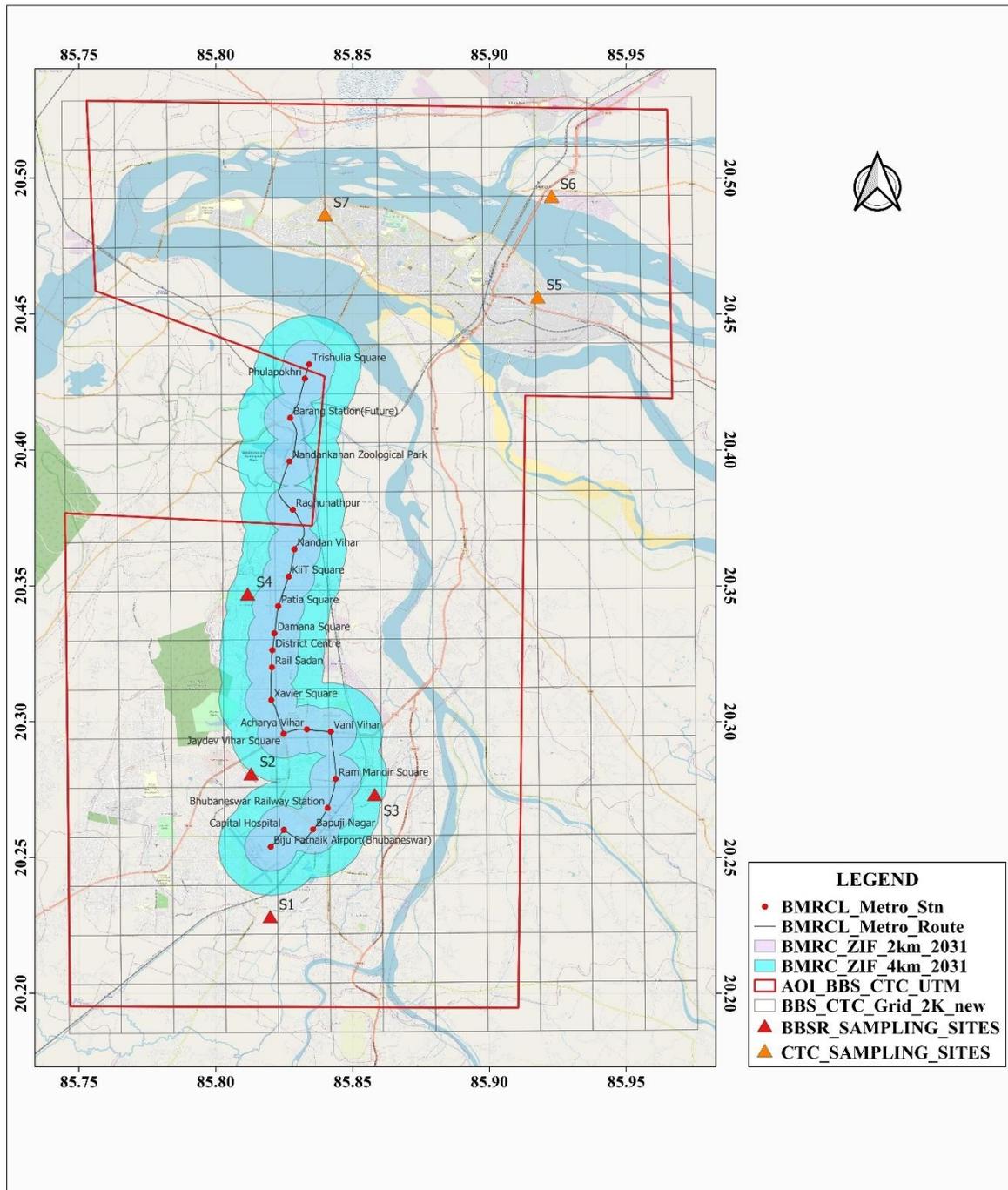


Figure 103 Map showing proposed Mass Rapid Transit System (MRTS) in Bhubaneswar region along with zones of influence (ZIF; 1 km radius and 2 km radius) around each station

### **5.3. Re-suspended Road Dust**

As discussed earlier, road dust re-suspension is a major source of PM emissions in Bhubaneswar region. Hence, stringent measures are required to be taken up to reduce the amount of silt (i.e. dust particles having aerodynamic diameter less than or equal to 75  $\mu\text{m}$ ) on roads. The impact of reducing silt loading on roads with high vehicular movement, followed by remaining roads is incorporated into emissions quantification under proposed scenarios in future years.

### **5.4. Industrial Sector**

Bhubaneswar is the state capital and there are no air polluting industries within the study domain. As per the data collected from Bhubaneswar regional office of State Pollution Control Board (OSPCB), there are a few industrial units which include food processing and textile units. For industries, it has been suggested to first maintain the air pollution control equipment properly and parallelly adopt Best Available Technologies (BAT) in their sector to achieve emission reductions in future years.

### **5.5. Residential, HRBE and Open Waste Burning Sectors**

The quantification of emissions for future years, from residential sector mainly considers the increase in population and changes in fuel usage pattern in Bhubaneswar region. The LPG penetration is estimated to increase gradually based on historic trends in the region whereas use of solid fuels such as wood and coal, for domestic cooking and heating applications is discouraged. Similar to residential sector, hotels and restaurants are assumed to reduce the solid fuel usage while promoting use of LPG for cooking and tandoor related applications. The open waste burning is assumed to decline in future years under different scenarios, except NFC owing to improved collection efficiency and effective solid waste management.

### **5.6. Brick Kilns Sector**

Currently, the FCBTK type brick kilns are operational in the Bhubaneswar region which are less efficient and more prone to air pollution. Further, they have no control devices installed, thereby aggravating the air pollution situation. While estimating the emissions for future years under different scenarios, it is proposed to shift the FCBTK type units to Vertical Shaft Brick Kilns (VSBK) or Zig-zag type brick kilns, which are comparatively less polluting, in a phase-wise manner.

## **5.7. Construction Sector**

With growth in economic activities and population the construction activities are also estimated to increase in upcoming years in the Bhubaneswar region. The three scenarios assume a gradual implementation of good construction practices (GCP), which may lead to PM emission reductions in the range 5 to 30%.

## **5.8. Crematoria Sector**

Although, the emissions originating from crematoria contribute less than 0.5% of total PM emissions at regional-scale, these emissions are very important for local scale air pollution problems. Hence, it is proposed to gradually shift the existing wood -based crematoria to electric crematoria till 2032 under different scenarios.

The sector-wise quantification of the considerations, explained above, in each of the four future scenarios is presented in subsequent sections.

## 5.9. No Further Control (NFC) Scenario

The NFC scenario considers the activities in each sector would increase following the sectoral growth rates and no additional controls would be implemented till years 2027 and 2032. The growth rates of different sectors have been adopted through review of published literature. Table 21 summarizes the sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032.

*Table 21 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 NFC scenario*

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• The major control measures considered for the transport sector include:                             <ul style="list-style-type: none"> <li>○ Increased penetration of BS-VI vehicles</li> </ul> </li> <li>• Refer Annexure-H for more details on penetration and applicability of each control measure listed above.</li> </ul>	VAHAN database, Odisha EV Policy, 2019 Assumptions
2.	RDST	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• No change in the silt loading on different road types in 2027 and 2032.</li> </ul>	Assumptions
3.	INDU	<ul style="list-style-type: none"> <li>• Industrial emissions are assumed to grow at an annual rate of 8.5%</li> <li>• No additional emission reduction measures in-place i.e. same as baseline year 2022</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
4.	RESI	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> <li>• The assumed LPG penetration in study area remains same as the baseline year 2022</li> </ul>	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5..	WAST	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> </ul>	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> <li>The MSW collection efficiency in the study area for years 2027 and 2032 would remain same as baseline year.</li> </ul>	
6.	HRBE	<ul style="list-style-type: none"> <li>The hotel and restaurants are assumed to follow an annual growth rate of 9.96%.</li> <li>The fuel usage characteristics and technology would remain same as the baseline year.</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	<ul style="list-style-type: none"> <li>The brick kilns are estimated to follow an annual growth rate of 6.4% till 2032.</li> <li>No change in the technology compared to baseline year</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	<ul style="list-style-type: none"> <li>The construction activities are assumed to increase at an annual growth rate of 6.4% till 2032</li> <li>No reduction in PM.</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> <li>The deaths in 2027 and 2032 are estimated using the crude death rate (CDR).</li> <li>No electric crematoria.</li> </ul>	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	ACFT	<ul style="list-style-type: none"> <li>The aircraft movements are assumed to grow at an annual rate of 9.56%</li> </ul>	AAI, 2022
11.	DSGN	<ul style="list-style-type: none"> <li>Residential and Commercial facilities are assumed to grow as per their sector-specific growth rates described above</li> <li>No additional control measures</li> </ul>	Odisha Economic Survey 2022-23, Assumptions

## 5.10. Business-As-Usual (BAU) Scenario

The BAU scenario considers the activity changes due to already planned policies/interventions by the government in years 2027 and 2032. The growth rates of different sectors have been adopted through review of published literature. Table 22 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2027 and 2032 BAU scenario.

*Table 22 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 BAU scenario*

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• The major control measures considered for the transport sector include:                             <ul style="list-style-type: none"> <li>○ Increased penetration of BS-VI vehicles</li> <li>○ Introduction of E20 fuel</li> <li>○ Increased electric vehicles (EV) penetration</li> <li>○ Increased CNG penetration</li> <li>○ Reduction in VKT due to increase in Non-motorized transport (NMT) share</li> <li>○ Introduction of Mass Rapid Transit System (MRTS) in Bhubaneswar region</li> <li>○ Improvement in public transport</li> <li>○ Reduction in highly polluting vehicles/ super-emitters</li> </ul> </li> <li>• Refer Annexure-H for more details on penetration and applicability of each control measure listed above.</li> </ul>	VAHAN database, Odisha EV Policy, 2019 BMRCL, 2023 Assumptions
2.	RDST	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• The silt loading on different road types calculated by assuming following:</li> </ul>	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> <li>○ Year 2027: 15% silt load reduction @ Highways and Major roads and 10% silt load reduction @ Inter, Minor and residential roads</li> <li>○ Year 2032: 30% silt load reduction @ Highways and Major roads and 20% silt load reduction @ Inter, Minor and residential roads</li> </ul>	
3.	INDU	<ul style="list-style-type: none"> <li>• Industrial emissions are assumed to grow at an annual rate of 8.5%</li> <li>• Assumed an emission reduction for Industries:               <ul style="list-style-type: none"> <li>○ 2027: 5% reduction in all pollutants w.r.t. corresponding NFC</li> <li>○ 2032: 10% reduction in all pollutants w.r.t. corresponding NFC</li> </ul> </li> </ul>	Odisha Economic Survey 2022-23, Assumptions
4.	RESI	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> <li>• The assumed LPG penetration in study area:               <ul style="list-style-type: none"> <li>○ Year 2027:                   <ol style="list-style-type: none"> <li>1. BMC HH: 90%</li> <li>2. Fringe HH: 80%</li> <li>3. Rural HH: 70%</li> <li>4. Slum HH: 70%</li> </ol> </li> <li>○ Year 2032:                   <ol style="list-style-type: none"> <li>1. BMC HH: 90%</li> <li>2. Fringe HH: 80%</li> <li>3. Rural HH: 75%</li> </ol> </li> </ul> </li> <li>• Slum HH: 70%</li> </ul>	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5..	WAST	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> <li>• The assumed MSW collection efficiency:               <ul style="list-style-type: none"> <li>○ Year 2027:</li> </ul> </li> </ul>	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ol style="list-style-type: none"> <li>1. BMC Area: 90%</li> <li>2. Fringe Area: 65%</li> <li>3. Rural Area: 65%</li> <li>4. Slum Area: 65%</li> </ol> <ul style="list-style-type: none"> <li>○ Year 2032: <ol style="list-style-type: none"> <li>1. BMC HH: 92%</li> <li>2. Fringe HH: 70%</li> <li>3. Rural HH: 70%</li> </ol> </li> <li>● Slum HH: 70%</li> </ul>	
6.	HRBE	<ul style="list-style-type: none"> <li>● The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. <ol style="list-style-type: none"> <li>4. 10% and 20% facilities would be converted from wood/coal to LPG in years 2027 and 2032, respectively.</li> </ol> </li> </ul>	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	<ul style="list-style-type: none"> <li>● The brick kilns are estimated to follow an annual growth rate of 6.4% till 2032. <ol style="list-style-type: none"> <li>4. No change in the technology compared to baseline year.</li> </ol> </li> </ul>	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	<ul style="list-style-type: none"> <li>● The construction activities are assumed to increase at growth rate of 6.4% till 2032</li> <li>● 5% reduction in PM due to adoption of Good construction practices and stricter enforcement.</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> <li>● The deaths in 2027 and 2032 are estimated using the crude death rate.</li> <li>● The 10% of the cremations would be converted to electricity-based cremations.</li> </ul>	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	ACFT	<ul style="list-style-type: none"> <li>● The aircraft movements are assumed to grow at an annual rate of 9.56%</li> </ul>	AAI, 2022

Sr. No.	Sector	Assumptions, considerations and controls	References
11.	DSGN	<ul style="list-style-type: none"><li>• Residential, commercial and industrial facilities are assumed to grow as per their sector-specific growth rates described above</li><li>• Daily usage hours are assumed to vary between 1 – 2 hours depending on locality</li></ul>	Odisha Economic Survey 2022-23, Assumptions

### 5.11. Scenario – I (SC-I)

The SC-I scenario considers the activity changes due to already planned policies/interventions by the government in years 2027 and 2032. The growth rates of different sectors have been adopted through review of published literature. Table 23 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2027 and 2032 SC-I.

*Table 23 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 SC-I scenario*

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• The major control measures considered for the transport sector include:                             <ul style="list-style-type: none"> <li>○ Increased penetration of BS-VI vehicles</li> <li>○ Introduction of E20 fuel</li> <li>○ Increased electric vehicles (EV) penetration</li> <li>○ Increased CNG penetration</li> <li>○ Reduction in VKT due to increase in Non-motorized transport (NMT) share</li> <li>○ Introduction of Mass Rapid Transit System (MRTS) in Bhubaneswar region</li> <li>○ Improvement in public transport</li> <li>○ Reduction in highly polluting vehicles/ super-emitters</li> </ul> </li> <li>• Refer Annexure-H for more details on penetration and applicability of each control measure listed above.</li> </ul>	VAHAN database, Odisha EV Policy, 2019 BMRCL, 2023 Assumptions
2.	RDST	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• The silt loading on different road types calculated by assuming following:                             <ul style="list-style-type: none"> <li>○ Year 2027: 30% silt load reduction @ Highways and Major roads and 20% silt load reduction @ Inter, Minor and residential roads</li> <li>○ Year 2032: 60% silt load reduction @ Highways and Major roads and 40% silt load reduction @ Inter, Minor and residential roads</li> </ul> </li> </ul>	Assumptions
3.	INDU	<ul style="list-style-type: none"> <li>• Industrial emissions are assumed to grow at an annual rate of 8.5%</li> </ul>	Odisha Economic

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> <li>• Assumed an emission reduction for Industries:               <ul style="list-style-type: none"> <li>○ 2027: 10% reduction in all pollutants w.r.t. corresponding NFC</li> <li>○ 2032: 25% reduction in all pollutants w.r.t. corresponding NFC</li> </ul> </li> </ul>	Survey 2022-23, Assumptions
4.	RESI	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> <li>• The assumed LPG penetration in study area:               <ul style="list-style-type: none"> <li>○ Year 2027:                   <ol style="list-style-type: none"> <li>1. BMC HH: 95%</li> <li>2. Fringe HH: 85%</li> <li>3. Rural HH: 75%</li> <li>4. Slum HH: 75%</li> </ol> </li> <li>○ Year 2032:                   <ol style="list-style-type: none"> <li>1. BMC HH: 95%</li> <li>2. Fringe HH: 90%</li> <li>3. Rural HH: 80%</li> </ol> </li> </ul> </li> <li>• Slum HH: 80%</li> </ul>	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	WAST	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> <li>• The assumed MSW collection efficiency:               <ul style="list-style-type: none"> <li>○ Year 2027:                   <ol style="list-style-type: none"> <li>1. BMC Area: 95%</li> <li>2. Fringe Area: 75%</li> <li>3. Rural Area: 75%</li> <li>4. Slum Area: 75%</li> </ol> </li> <li>○ Year 2032:                   <ol style="list-style-type: none"> <li>1. BMC HH: 95%</li> <li>2. Fringe HH: 90%</li> <li>3. Rural HH: 80%</li> </ol> </li> </ul> </li> <li>• Slum HH: 80%</li> </ul>	Assumptions
6.	HRBE	<ul style="list-style-type: none"> <li>• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%.               <ol style="list-style-type: none"> <li>4. 20 and 40% facilities would be converted from wood/coal to LPG</li> </ol> </li> </ul>	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		in years 2027 and 2032, respectively.	
7.	BRIC	<ul style="list-style-type: none"> <li>The brick kilns are estimated to follow a growth rate of 6.4% till 2032.</li> <li>All Clamp type brick kilns within BMC area would be converted to VSBK/Zig-Zag kilns by 2027.</li> <li>4. All brick kilns within AOI are converted to VSBK/Zig-Zag technology by 2032.</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	<ul style="list-style-type: none"> <li>The construction activities are assumed to increase at growth rate of 6.4% till 2032</li> <li>10 and 15% reduction in PM for years 2027 and 2032, respectively, due to adoption of Good construction practices and stricter enforcement.</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> <li>The deaths in 2027 and 2032 are estimated using the crude death rate.</li> <li>The 25% and 75% of the cremations would be converted to electricity-based cremations, by 2027 and 2032, respectively.</li> </ul>	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	ACFT	<ul style="list-style-type: none"> <li>The aircraft movements are assumed to grow at an annual rate of 9.56%</li> </ul>	AAI, 2022
11.	DSGN	<ul style="list-style-type: none"> <li>Residential, commercial and industrial facilities are assumed to grow as per their sector-specific growth rates described above</li> <li>Daily usage hours are assumed to vary between 0.75 – 1.5 hours depending on locality</li> </ul>	Odisha Economic Survey 2022-23, Assumptions

## 5.12. Scenario – II (SC-II)

The SC-II scenario considers the activity changes due to already planned policies/interventions by the government in years 2027 and 2032. The growth rates of different sectors have been adopted through review of published literature. Table 24 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2027 and 2032 SC-II scenario.

*Table 24 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 SC-II scenario*

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• The major control measures considered for the transport sector include:                             <ul style="list-style-type: none"> <li>○ Increased penetration of BS-VI vehicles</li> <li>○ Introduction of E20 fuel</li> <li>○ Increased electric vehicles (EV) penetration</li> <li>○ Increased CNG penetration</li> <li>○ Reduction in VKT due to increase in Non-motorized transport (NMT) share</li> <li>○ Introduction of Mass Rapid Transit System (MRTS) in Bhubaneswar region</li> <li>○ Improvement in public transport</li> <li>○ Reduction in highly polluting vehicles/ super-emitters</li> </ul> </li> <li>• Refer Annexure-H for more details on penetration and applicability of each control measure listed above.</li> </ul>	VAHAN database, Odisha EV Policy, 2019 BMRCL, 2023 Assumptions
2.	RDST	<ul style="list-style-type: none"> <li>• The vehicles in Bhubaneswar region are estimated to grow at a CAGR of 6.31% till 2032.</li> <li>• The silt loading on different road types calculated by assuming following:                             <ul style="list-style-type: none"> <li>○ Year 2027: 50% silt load reduction @ Highways and Major roads and 30% silt load reduction @ Inter, Minor and residential roads</li> <li>○ Year 2032: 90% silt load reduction @ Highways and Major roads and 60% silt load reduction @ Inter, Minor and residential roads</li> </ul> </li> </ul>	Assumptions
3.	INDU	<ul style="list-style-type: none"> <li>• Industrial emissions are assumed to grow at an annual rate of 8.5%</li> <li>• Assumed an emission reduction for Industries:</li> </ul>	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> <li>○ 2027: 25% reduction in all pollutants w.r.t. corresponding NFC</li> <li>○ 2032: 50% reduction in all pollutants w.r.t. corresponding NFC</li> </ul>	
4.	RESI	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> <li>• The assumed LPG penetration in study area:                             <ul style="list-style-type: none"> <li>○ Year 2027:                                     <ol style="list-style-type: none"> <li>1. BMC HH: 98%</li> <li>2. Fringe HH: 90%</li> <li>3. Rural HH: 80%</li> <li>4. Slum HH: 80%</li> </ol> </li> <li>○ Year 2032:                                     <ol style="list-style-type: none"> <li>1. BMC HH: 100%</li> <li>2. Fringe HH: 98%</li> <li>3. Rural HH: 95%</li> </ol> </li> </ul> </li> <li>• Slum HH: 95%</li> </ul>	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	WAST	<ul style="list-style-type: none"> <li>• The population is estimated based on historic population growth rate.</li> <li>• The assumed MSW collection efficiency:                             <ul style="list-style-type: none"> <li>○ Year 2027:                                     <ol style="list-style-type: none"> <li>1. BMC Area: 98%</li> <li>2. Fringe Area: 85%</li> <li>3. Rural Area: 80%</li> <li>4. Slum Area: 80%</li> </ol> </li> <li>○ Year 2032:                                     <ol style="list-style-type: none"> <li>1. BMC HH: 98%</li> <li>2. Fringe HH: 95%</li> <li>3. Rural HH: 95%</li> </ol> </li> </ul> </li> <li>• Slum HH: 95%</li> </ul>	Assumptions
6.	HRBE	<ul style="list-style-type: none"> <li>• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%.                             <ol style="list-style-type: none"> <li>4. 30 and 50% facilities would be converted from wood/coal to LPG</li> </ol> </li> </ul>	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		by years 2027 and 2032, respectively.	
7.	BRIC	<ul style="list-style-type: none"> <li>The brick kilns are estimated to follow a growth rate of 6.4% till 2032.</li> <li>All brick kilns within BMC area would be converted to VSBK/Zig-Zag kilns by 2027.</li> <li>4. All brick kilns within study area would be converted to VSBK/Zig-Zag technology by 2032.</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	<ul style="list-style-type: none"> <li>The construction activities are assumed to increase at growth rate of 6.4% till 2032</li> <li>20 and 30% reduction in PM for years 2027 and 2032, respectively, due to adoption of Good construction practices and stricter enforcement.</li> </ul>	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> <li>The deaths in 2027 and 2032 are estimated using the crude death rate.</li> <li>The 50% and 100% of the crematoria would be converted to electricity, by 2027 and 2032, respectively.</li> </ul>	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	ACFT	<ul style="list-style-type: none"> <li>The aircraft movements are assumed to grow at an annual rate of 9.56%</li> </ul>	AAI, 2022
11.	DSGN	<ul style="list-style-type: none"> <li>Residential, commercial and industrial facilities are assumed to grow as per their sector-specific growth rates described above</li> <li>Daily usage hours are assumed to vary between 0.5 to 1 hours depending on locality</li> </ul>	Odisha Economic Survey 2022-23, Assumptions

### **5.13. Projected Emissions for 2027 and 2032**

This section discusses the projected emissions of pollutants under consideration with implementation of considered scenarios in 2027 and 2032 in Bhubaneswar region. As discussed earlier, these scenarios consider implementation of various control measures explained in Section 5.12 in Bhubaneswar region with varying factors for 2027 and 2032. Table 25 and Figures 104 to 108 presents the summary of estimated emissions (tonnes per year) of selected pollutants for four scenarios in Bhubaneswar region for years 2027 and 2032.

The No further control (NFC) scenario emissions are compared against the baseline year emissions of 2022. The NFC scenario projections in Bhubaneswar region indicate a potential increase in PM<sub>10</sub> emissions to 10,387 tonnes per year in 2027 i.e. an increase of 34.6% w.r.t. baseline year 2022 and to 13,542 tonnes per year in 2032 i.e. an increase of 75.5% w.r.t. baseline year 2022. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to reach to 5,527 (26.8%) and 6,596 tonnes per year (i.e. 51.3%) in 2027 and 2032, respectively. The projected emissions of SO<sub>2</sub> indicate a potential increase to 1,508 tonnes per year in 2027 i.e. an increase of 34.1% w.r.t. baseline year 2022 and to 1,864 tonnes per year in 2032 i.e. an increase of 65.7% w.r.t. baseline year 2022. The projected emissions of NO<sub>x</sub> indicate a potential increase to 20,415 tonnes per year in 2027 i.e. an increase of 19.1% w.r.t. baseline year 2022 and to 21,055 tonnes per year in 2032 i.e. an increase of 22.8% w.r.t. baseline year 2022. The CO emissions are expected to increase to 68,864 tonnes per year in 2027 i.e. an increase of 25.9% and 83,474 tonnes per year in 2032 i.e. an increase of 52.6% w.r.t. baseline year 2022.

The BAU projections in Bhubaneswar indicate a potential decrease of PM<sub>10</sub> emissions to 9,427 tonnes per year in 2027 i.e. a decrease of 9.2 % w.r.t. NFC\_2027 and to 10,347 tonnes per year in 2032 i.e. a decrease of 23.6% w.r.t. NFC 2032. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to decrease to 5,130 (-7.2%) and 5,395 tonnes per year (i.e. -18.2%) in 2027 and 2032, respectively. Sulphur dioxide (SO<sub>2</sub>) emissions are projected to slightly increase by 0.9% (i.e. 1,522 tonnes per year) and decrease by 5.4% (i.e.1,762 tonnes per year) in 2027 and 2032, respectively relative to their respective NFC scenarios. The projected emissions of NO<sub>x</sub> indicate a potential reduction to 21,180 tonnes per year in 2027 i.e. an increase of 3.7% w.r.t. NFC\_2027 and to 21,674 tonnes per year in 2032 i.e. an increase of 2.9% w.r.t. NFC 2032. The CO emissions are expected to decrease to 66,371 tonnes per year

in 2027 i.e. a decrease of 3.6% w.r.t. NFC\_2027 and 76,948 tonnes per year in 2032 i.e. a decrease of 7.8% w.r.t. NFC 2032.

The SC-I projections in Bhubaneswar region indicate a potential decrease of PM<sub>10</sub> emissions to 8,036 tonnes per year in 2027 i.e. a decrease of 22.6% w.r.t. NFC 2027 and to 7,567 tonnes per year in 2032 i.e. a decrease of 44.1% w.r.t. NFC 2032. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to decrease to 4,372 (-20.9%) and 7,567 tonnes per year (i.e. -39.9%) in 2027 and 2032, respectively. Sulphur dioxide emissions are projected to decline by 25.6% (i.e. 1122 tonnes per year) and 31.6% (i.e. 1274 tonnes per year) in 2027 and 2032, respectively, relative to their respective NFC scenarios. Similarly, projected emissions of NO<sub>x</sub> indicate a potential reduction to 19441 tonnes per year in 2027 i.e. a decrease of 4.8% w.r.t. NFC 2027 and to 17903 tonnes per year in 2032 i.e. a decrease of 15% w.r.t. NFC 2032. The CO emissions are expected to decrease to 61299 tonnes per year in 2027 i.e. a decrease of 11% w.r.t. NFC 2027 and 68211 tonnes per year in 2032 i.e. a decrease of 18.3% w.r.t. NFC 2032.

The SC-II projections in Bhubaneswar region indicate a potential decrease of PM<sub>10</sub> emissions to 6581 tonnes per year in 2027 i.e. a decrease of 36.6% w.r.t. NFC 2027 and to 4382 tonnes per year in 2032 i.e. a decrease of 67.6% w.r.t. NFC 2032. The finer PM fraction i.e. PM<sub>2.5</sub> emissions are also estimated to decrease to 3666 (i.e. -33.7%) and 2599 tonnes per year (i.e. -60.6%) in 2027 and 2032, respectively. Sulphur dioxide (SO<sub>2</sub>) emissions are projected to decline by 38.4% (i.e. 929 tonnes per year) and 61.3% (i.e. 721 tonnes per year) in 2027 and 2032, respectively, relative to their respective NFC scenarios. Similarly, the projected emissions of NO<sub>x</sub> indicate a potential reduction to 17517 tonnes per year in 2027 i.e. a decrease of 14.2% w.r.t. NFC 2027 and to 15186 tonnes per year in 2032 i.e. a decrease of 27.9% w.r.t. NFC 2032. The CO emissions are expected to decrease to 56577 tonnes per year in 2027 i.e. a decrease of 17.8% w.r.t. NFC 2027 and 59375 tonnes per year in 2032 i.e. a decrease of 28.9% w.r.t. NFC 2032.

Table 25 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Bhubaneswar region for years 2022, 2027 and 2032

Year	Scenario	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>x</sub>	CO
2022	BASE	7,714	4,359	1,125	17,142	54,698
2027	NFC	10,387	5,527	1,508	20,415	68,864
	BAU	9,427	5,130	1,522	21,180	66,371
	SC_I	8,036	4,372	1,122	19,441	61,299
	SC_II	6,581	3,666	929	17,517	56,577
2032	NFC	13,542	6,596	1,864	21,055	83,474
	BAU	10,347	5,395	1,762	21,674	76,948
	SC_I	7,567	3,966	1,274	17,903	68,211
	SC_II	4,382	2,599	721	15,186	59,375

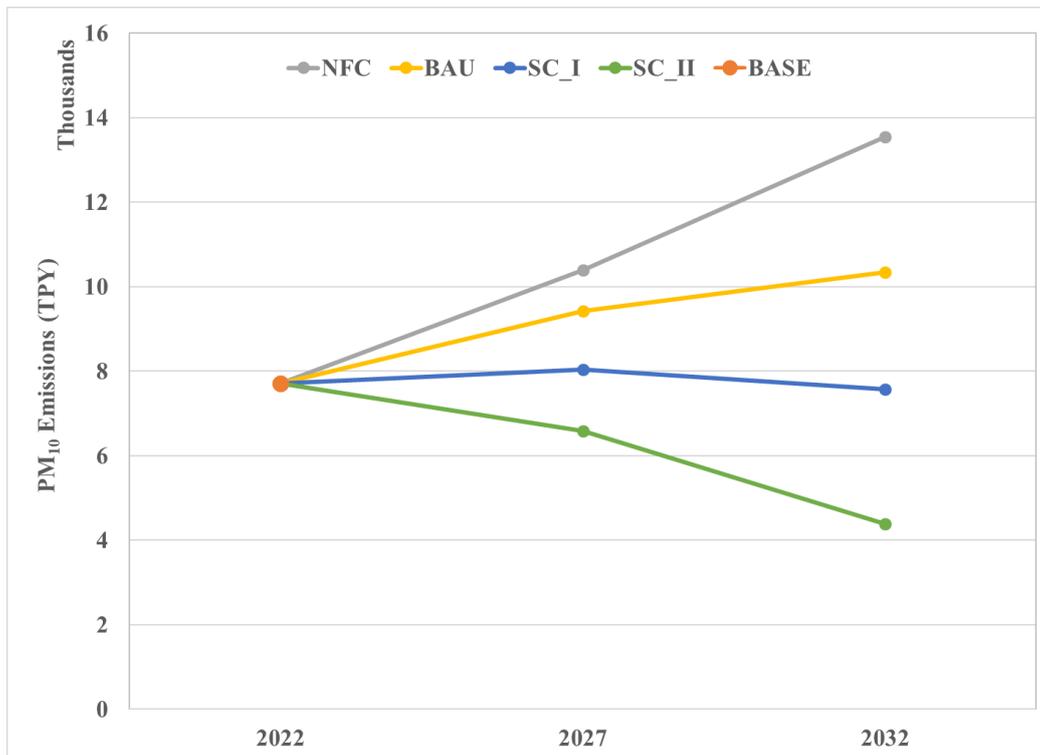


Figure 104 PM10 Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

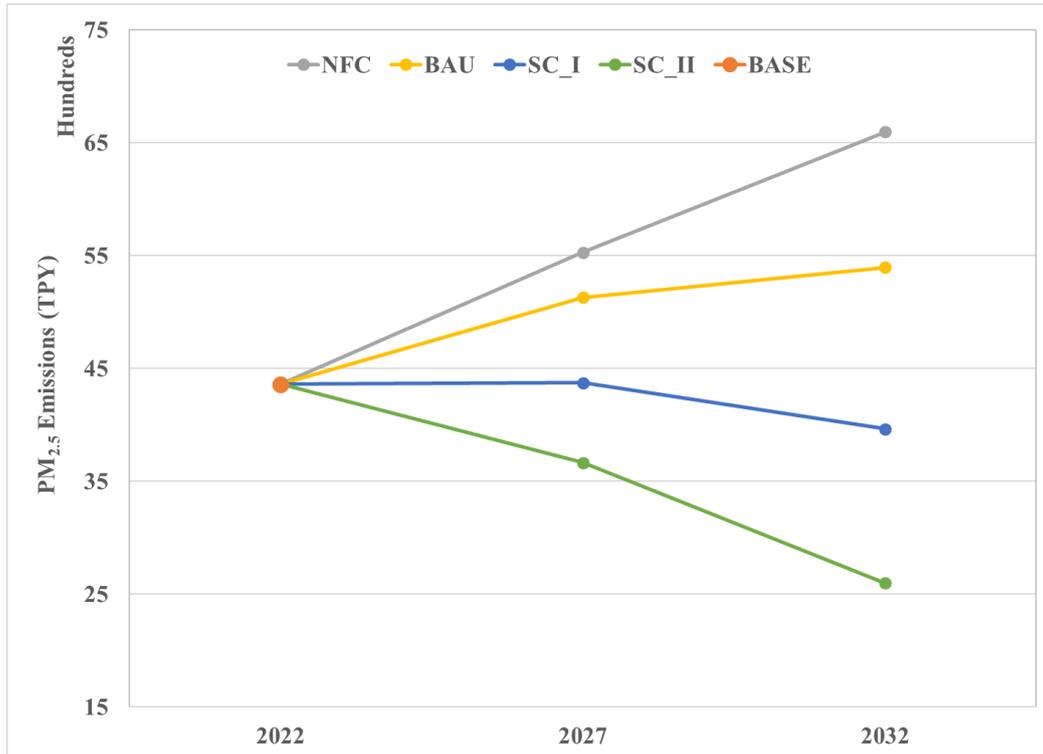


Figure 105 PM<sub>2.5</sub> Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

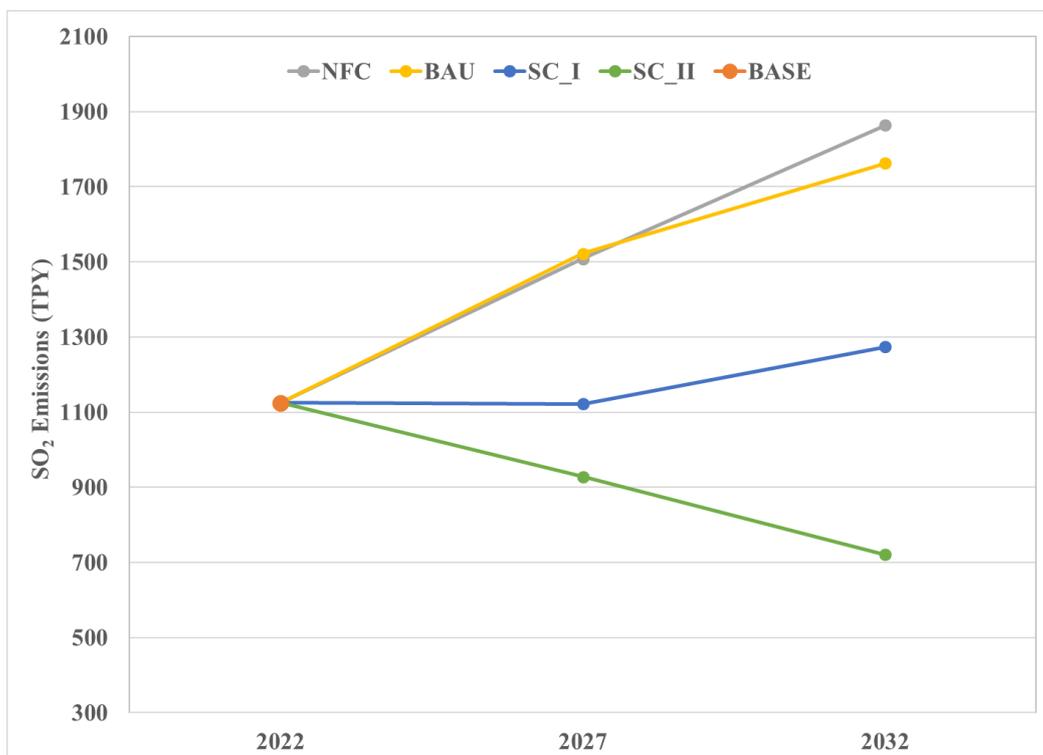


Figure 106 SO<sub>2</sub> Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

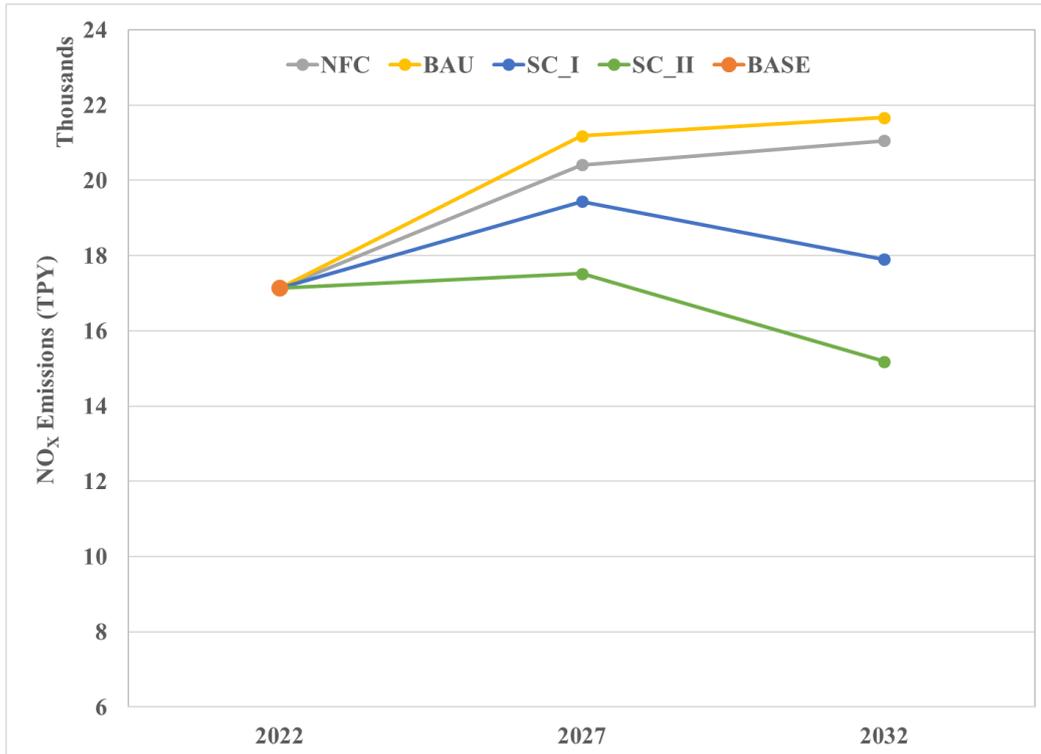


Figure 107 NO<sub>x</sub> Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

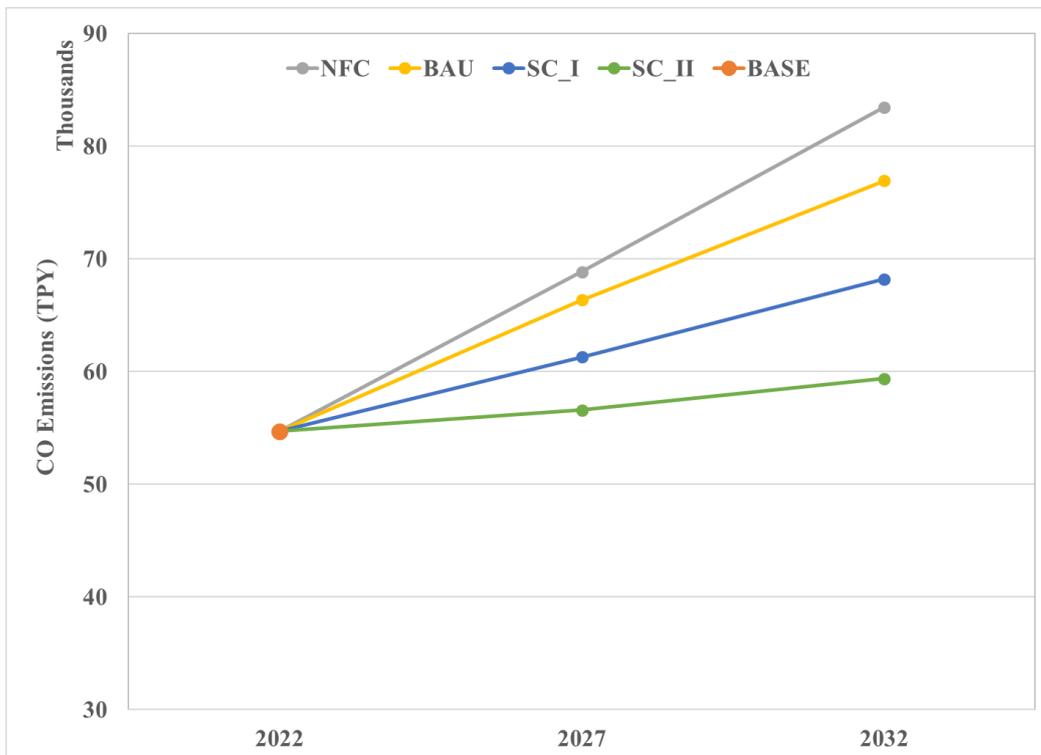


Figure 108 CO Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

### **5.13.1. Sector-wise emission reduction potentials**

Table 26 and Fig. 109-113 shows sector-wise and total estimated emission reduction potential (%) of pollutants w.r.t. respective NFC scenarios in Bhubaneswar region for years 2027 and 2032. The total emissions of particulate matter in 2027 can be reduced upto maximum 36.64% and 33.68% in PM<sub>10</sub> and PM<sub>2.5</sub>, respectively w.r.t. NFC 2027 scenario. Similarly, total emissions of particulate matter in 2032 can be reduced upto maximum 67.64% and 60.60% in PM<sub>10</sub> and PM<sub>2.5</sub>, respectively w.r.t. NFC 2032 scenario. In year 2032 the sectoral emission reduction potential for PM<sub>10</sub> in decreasing order of reduction are road dust (upto 41.36%), open waste burning (upto 8.06%), residential (upto 6.58%) and hotels, restaurants, bakeries and eateries (upto 5.02%). Remaining PM<sub>10</sub> emission sources together contribute 6.62% reduction in PM<sub>10</sub>. Similarly, for PM<sub>2.5</sub> significant emission reductions can be obtained in re-suspended road dust (upto 20.54%), open waste burning (upto 15.37%), residential (upto 8.51%) and hotels, restaurants, bakeries and eateries (upto 6.54%).

**Table 26 Sector-wise estimated emission reduction potential (%) for PM<sub>10</sub> and PM<sub>2.5</sub> w.r.t. respective NFC scenarios in Bhubaneswar region**

Year	Sector	PM <sub>10</sub>			PM <sub>2.5</sub>		
		BAU	SC-I	SC-II	BAU	SC-I	SC-II
2027	TRAN	-0.13%	-0.59%	-1.29%	-0.2%	-1.0%	-2.19%
	RDST	-5.84%	-11.51%	-18.90%	-2.7%	-5.2%	-8.59%
	RESI	-1.16%	-3.15%	-4.55%	-1.5%	-3.6%	-5.37%
	WAST	-1.17%	-4.19%	-5.80%	-2.0%	-7.3%	-10.11%
	HRBE	-0.98%	-1.96%	-2.94%	-1.2%	-2.3%	-3.50%
	CONS	-0.22%	-0.44%	-0.88%	-0.1%	-0.2%	-0.41%
	DSGN	0.31%	-0.68%	-2.02%	0.6%	-1.1%	-3.26%
	WBDT	0.00%	0.00%	0.00%	0.0%	0.0%	0.00%
	INDU	-0.01%	-0.02%	-0.04%	0.0%	0.0%	-0.05%
	BRIC	0.00%	0.00%	-0.01%	0.0%	0.0%	0.00%
	CREM	-0.04%	-0.11%	-0.21%	0.0%	-0.1%	-0.20%
	ACFT	0.00%	0.00%	0.00%	0.0%	0.0%	0.00%
	<b>Total</b>	<b>-9.24%</b>	<b>-22.64%</b>	<b>-36.64%</b>	<b>-7.18%</b>	<b>-20.89%</b>	<b>-33.68%</b>
2032	TRAN	-0.48%	-1.06%	-1.97%	-0.88%	-1.96%	-3.63%
	RDST	-17.17%	-27.07%	-41.36%	-8.53%	-13.45%	-20.54%
	RESI	-1.68%	-3.83%	-6.58%	-2.36%	-5.21%	-8.51%
	WAST	-2.34%	-5.64%	-8.06%	-4.45%	-10.75%	-15.37%
	HRBE	-2.01%	-4.02%	-5.02%	-2.62%	-5.23%	-6.54%
	CONS	-0.23%	-0.68%	-1.36%	-0.12%	-0.35%	-0.70%
	DSGN	0.50%	-1.46%	-2.69%	0.95%	-2.59%	-4.81%
	WBDT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	INDU	-0.02%	-0.04%	-0.08%	-0.02%	-0.05%	-0.10%
	BRIC	-0.01%	-0.05%	-0.16%	0.00%	-0.01%	-0.04%
	CREM	-0.18%	-0.27%	-0.37%	-0.18%	-0.28%	-0.37%
	ACFT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	<b>Total</b>	<b>-23.60%</b>	<b>-44.13%</b>	<b>-67.64%</b>	<b>-18.21%</b>	<b>-39.88%</b>	<b>-60.60%</b>

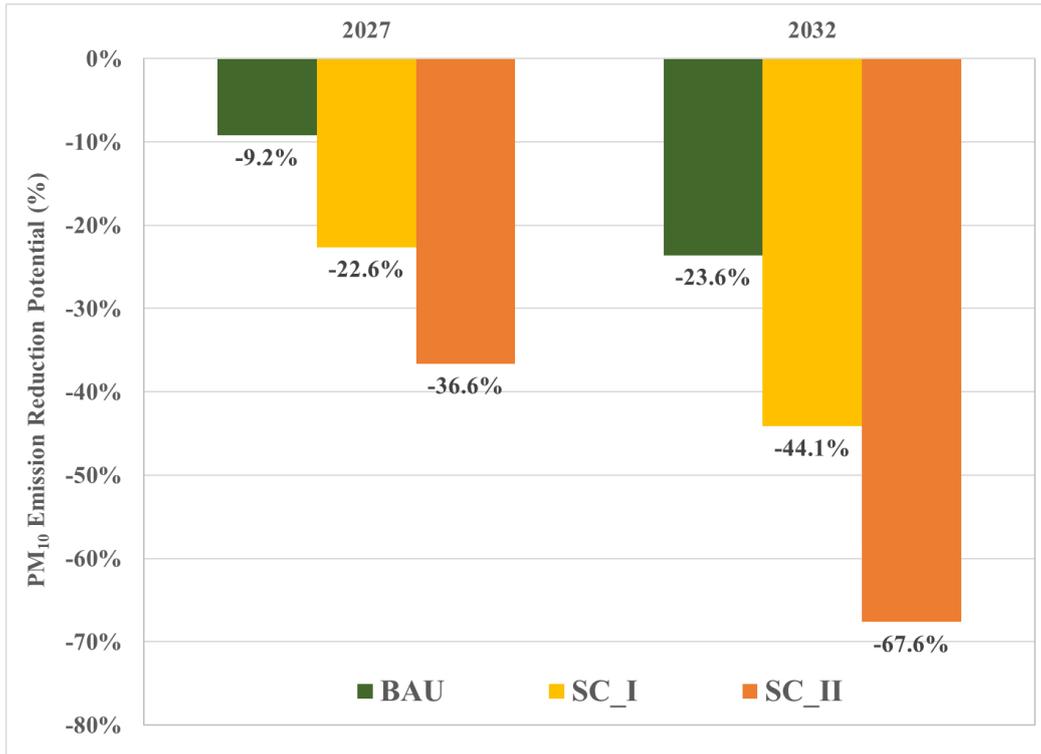


Figure 109 PM<sub>10</sub> Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

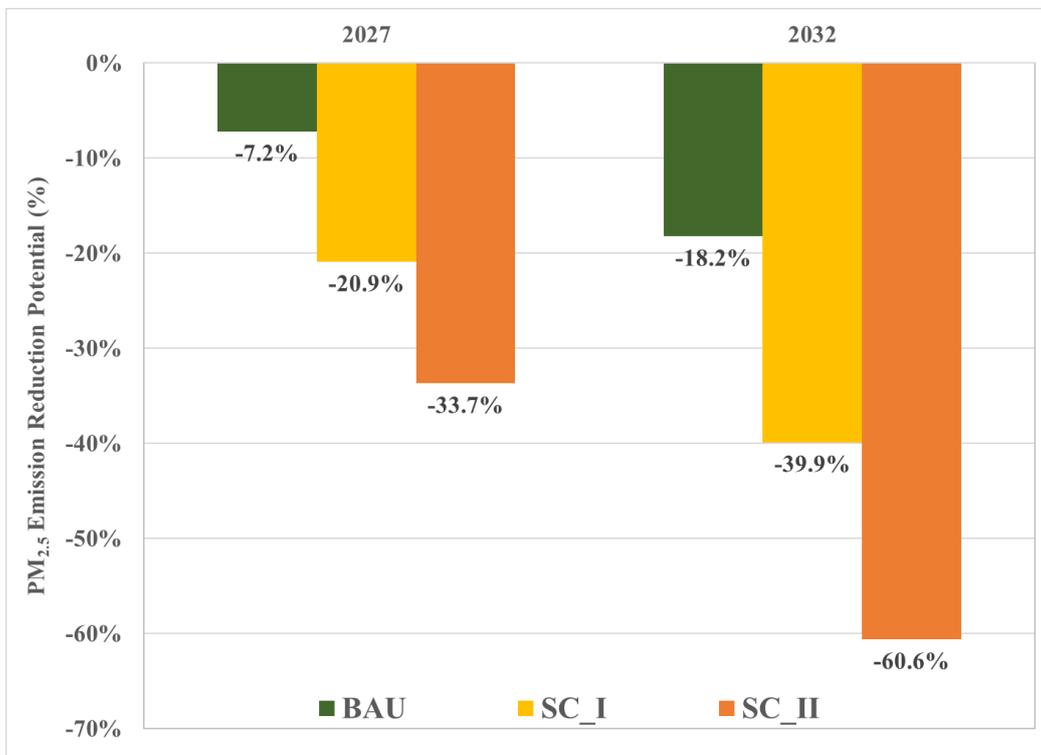


Figure 110 PM<sub>2.5</sub> Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

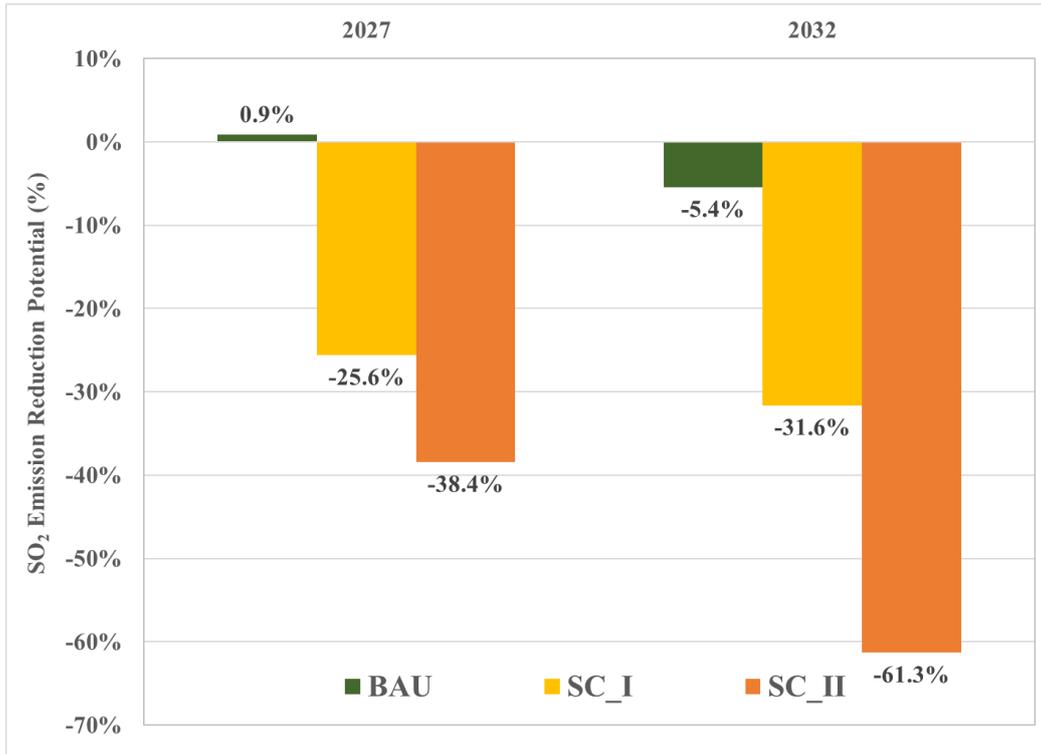


Figure 111 SO<sub>2</sub> Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

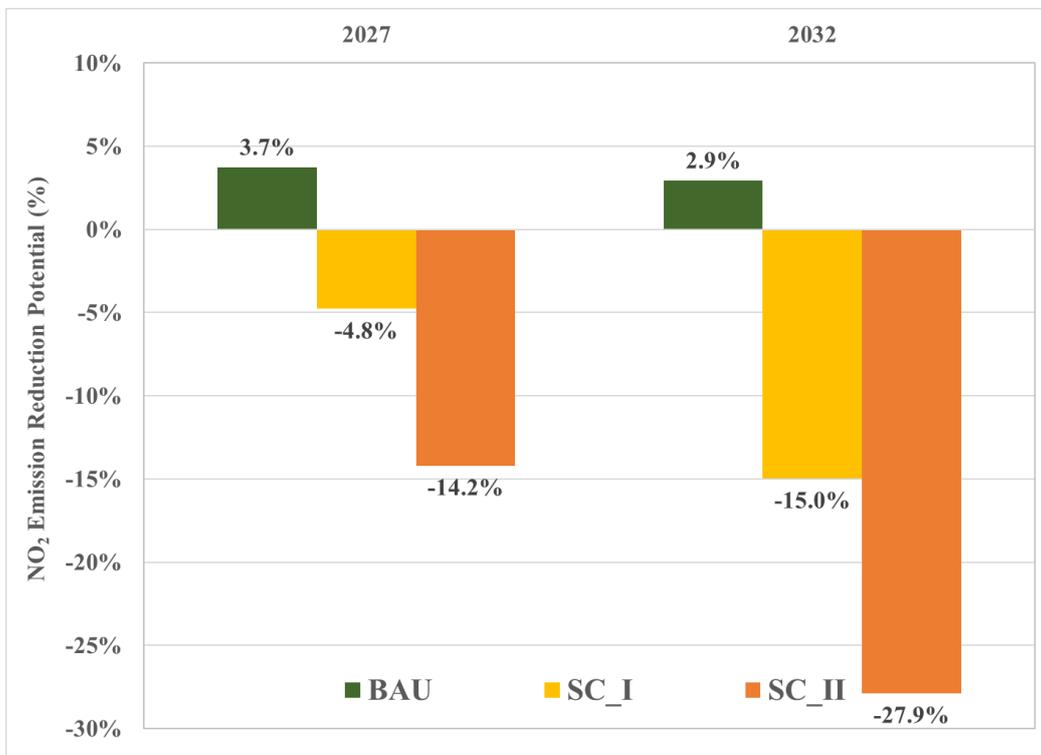


Figure 112 NO<sub>x</sub> Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

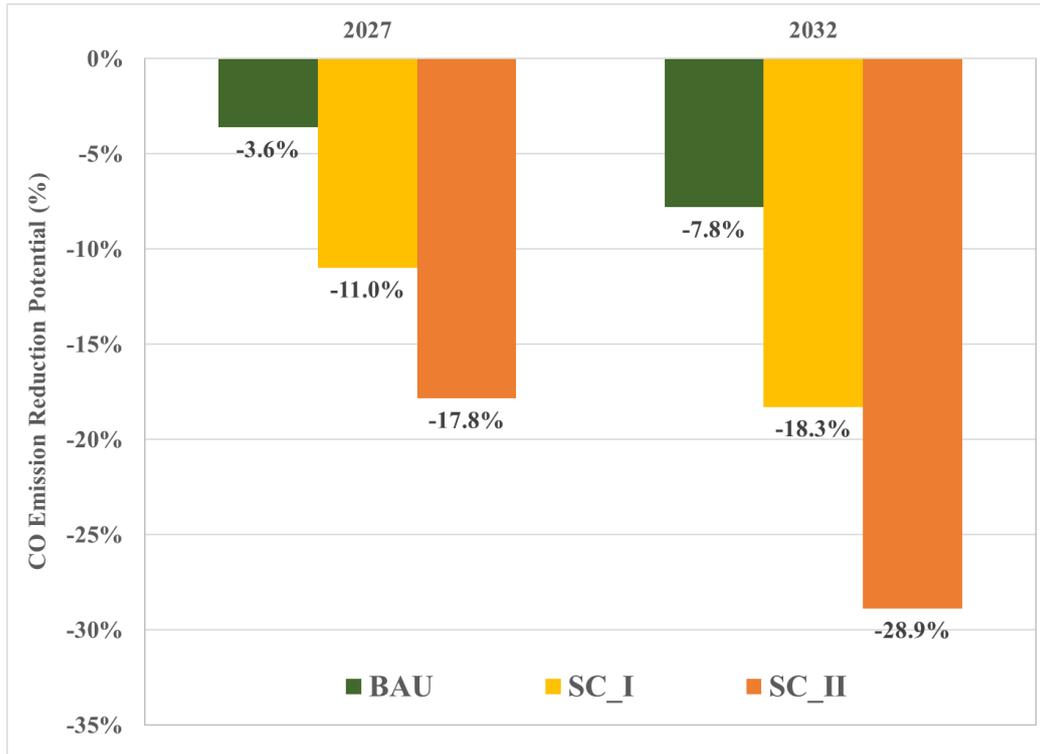


Figure 113 CO Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

## 5.14. Air Quality Benefits

Air quality benefits of four designed scenarios were assessed for years 2027 and 2032 using AERMOD modelled annual mean pollutant concentrations in Bhubaneswar-Cuttack region. The spatial distribution of pollutant (PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>2</sub>, CO) concentration levels over Bhubaneswar-Cuttack region are plotted in gridded format using QGIS. The annual mean concentrations are plotted for year 2027 and 2032 for different scenarios.

In general, the highest estimated concentrations of particulate matter i.e. PM<sub>10</sub> and PM<sub>2.5</sub> are observed towards central parts of Bhubaneswar and Cuttack cities as well as southern parts of the study domain. These highest concentrations can be attributed to the air polluting sources such exhaust emissions, road dust emissions due to vehicular movement, fuel combustion in households and commercial facilities. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2027 and 2032 due to proposed changes in technology and fuels of vehicles such as EV adoption, increased penetration of BS-VI vehicles, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, NMT & improvement in public transport, introduction of mass rapid transit

system (MRTS), increasing use of clean fuel for cooking, improved waste collection efficiency, adoption of Zig-zag type brick kilns and various other control strategies considered in different scenarios.

As shown in Fig 114-115, the PM<sub>10</sub> concentrations for NFC scenario in 2027 and 2032, are mainly concentrated in the central parts of the Bhubaneswar and Cuttack cities. The domain-averaged annual PM<sub>10</sub> concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 64.4, 59.7, 54.3, and 48.3 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual PM<sub>10</sub> concentrations during year 2032 are estimated to be 78.2, 64.0, 52.3, and 38.5 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 6.7%, 14.3%, and 22.8% in 2027 and 16.3%, 30.2%, and 46.3% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 116-117, the PM<sub>2.5</sub> concentrations, are also concentrated in central parts of the Bhubaneswar and Cuttack cities. The domain-averaged annual PM<sub>2.5</sub> concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 29.0, 27.0, 24.5, and 22.0 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual PM<sub>2.5</sub> concentrations during year 2032 are estimated to be 33.4, 28.0, 23.1, and 17.8 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 6.3%, 14.4%, and 22.4% in 2027 and 15.0%, 28.7%, and 43.4% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 118-119, the SO<sub>2</sub> concentrations, are concentrated in the central parts of the Bhubaneswar and Cuttack cities. The domain-averaged annual SO<sub>2</sub> concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 4.3, 4.2, 3.7, and 3.4 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual SO<sub>2</sub> concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) are estimated to be 4.9, 4.6, 3.9 and 3.2 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios in year 2032, respectively. With implementation of control measures considered in different scenarios, an estimated reduction

of 3.0%, 11.8%, and 17.7% in 2027 and 4.7%, 17.2%, 31.2% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 120-121, the NO<sub>2</sub> concentrations, are also concentrated in central parts of the Bhubaneswar and Cuttack cities. Ambient NO<sub>2</sub> concentrations are mainly driven by ground-level line sources and are found to be highest in the vicinity of highways and major roads where heavy vehicle movement is high. The domain-averaged annual NO<sub>2</sub> concentrations (i.e. mean of annual concentrations of 26 receptors in the study domain) estimated by AERMOD during four scenarios are 13.5, 13.4, 13.2, and 12.9 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual NO<sub>2</sub> concentrations during year 2032 are estimated to be 13.5, 13.2, 12.8 and 12.3 µg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 0.2%, 1.8%, and 3.8% in 2027. With implementation of control measures considered in different scenarios, an estimated reduction of 1.7%, 4.5%, and 8.0% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 122-123, the CO concentrations, are also concentrated in the central, parts of the Bhubaneswar and Cuttack cities. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 0.586, 0.570, 0.546, and 0.523 mg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated to be 0.657, 0.619, 0.581, and 0.539 mg/m<sup>3</sup> for NFC, BAU, SC-I and SC-II scenarios in year 2032, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 2.5%, 6.2%, and 9.8% in 2027 and 5.3%, 10.6%, 16.6% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

It is important to note that, these are domain averaged values and pollutant reductions are likely to vary significantly over the study domain. The values are highest at the receptors very close to sources.

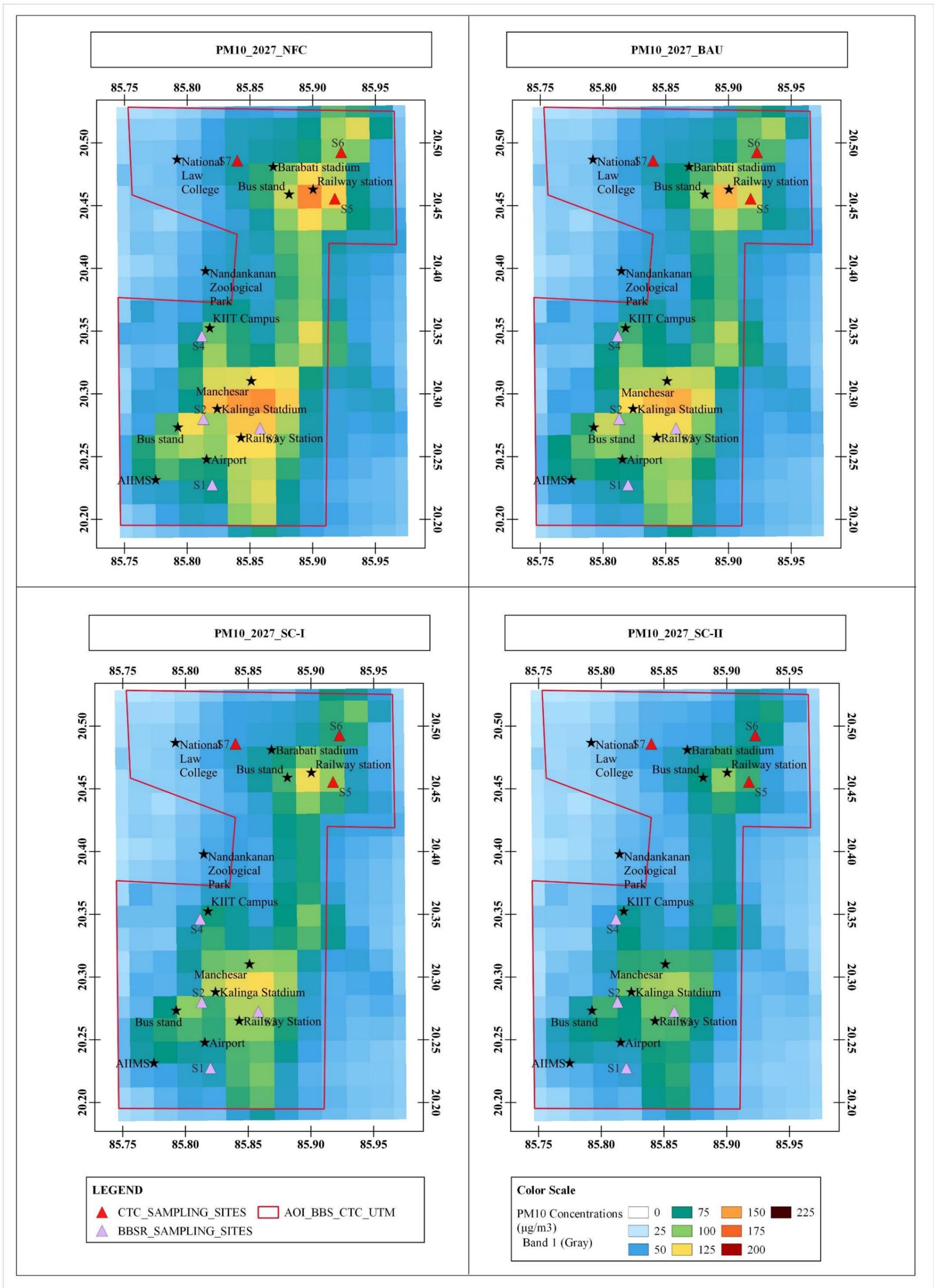


Figure 114 Spatial distribution of annual mean PM<sub>10</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2027 over Bhubaneswar-Cuttack region

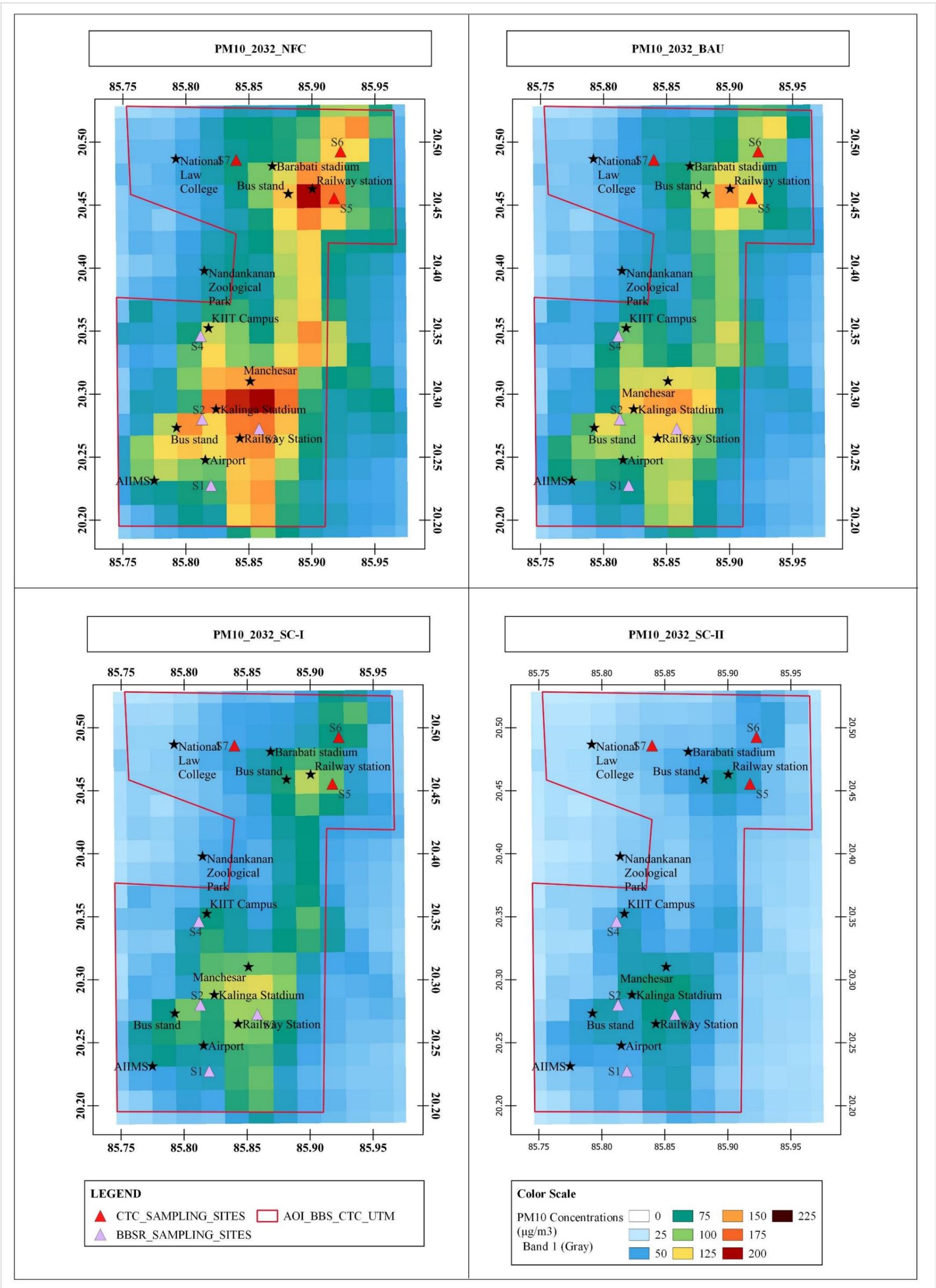


Figure 115 Spatial distribution of annual mean PM<sub>10</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2032 over Bhubaneswar-Cuttack region

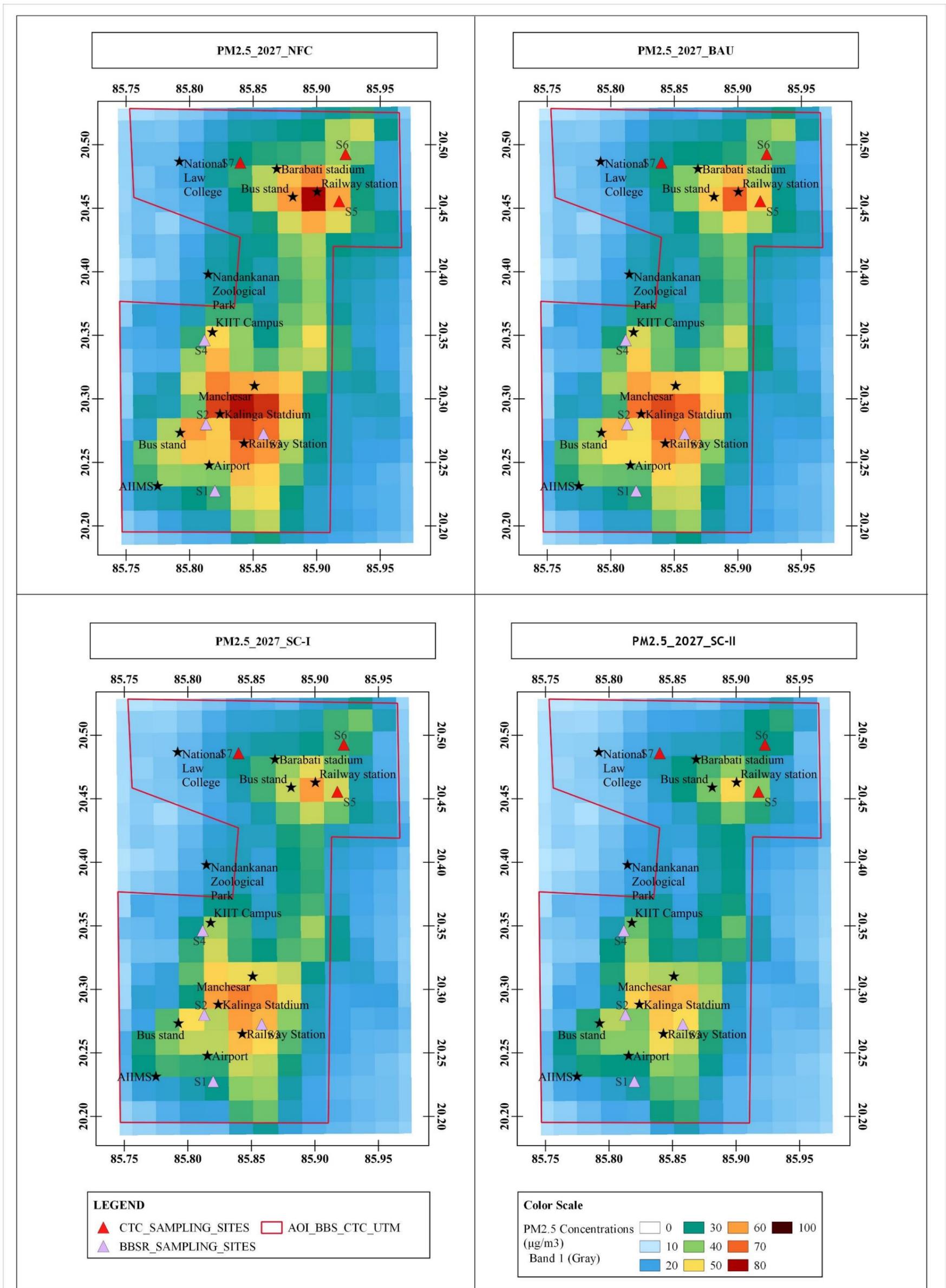


Figure 116 Spatial distribution of annual mean PM<sub>2.5</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2027 over Bhubaneswar-Cuttack region

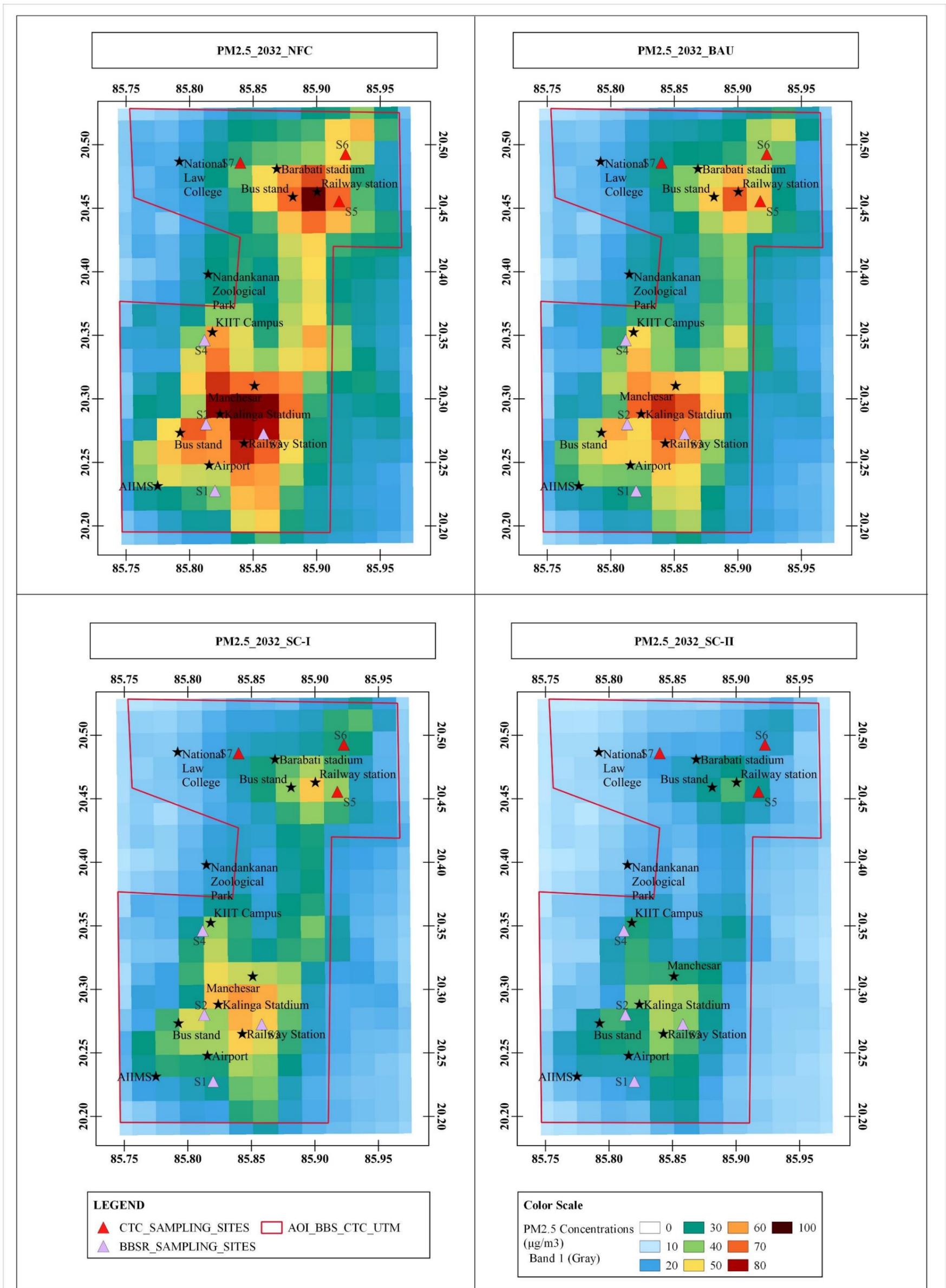


Figure 117 Spatial distribution of annual mean PM<sub>2.5</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2032 over Bhubaneswar-Cuttack region

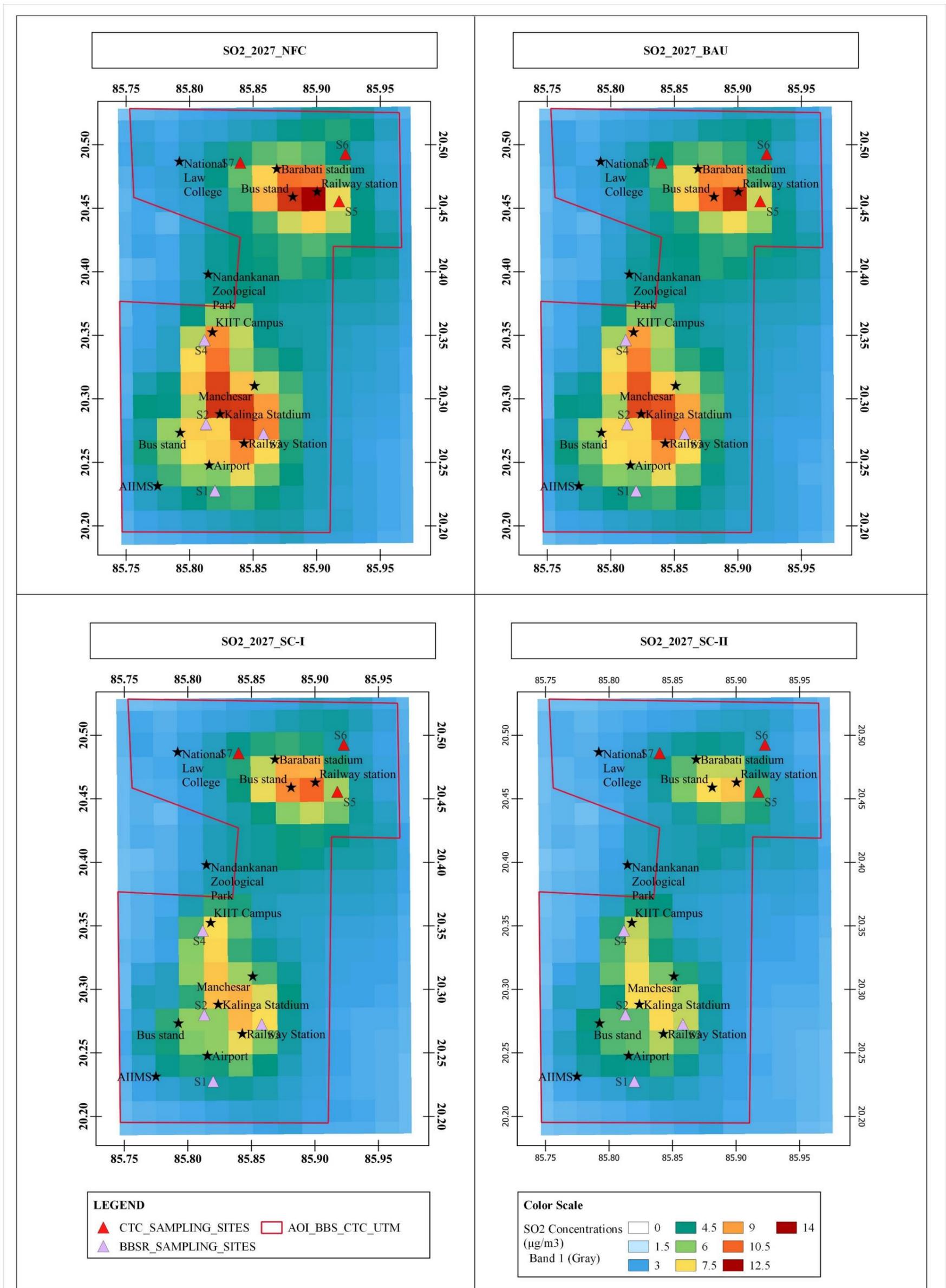


Figure 118 Spatial distribution of annual mean SO<sub>2</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2027 over Bhubaneswar-Cuttack region

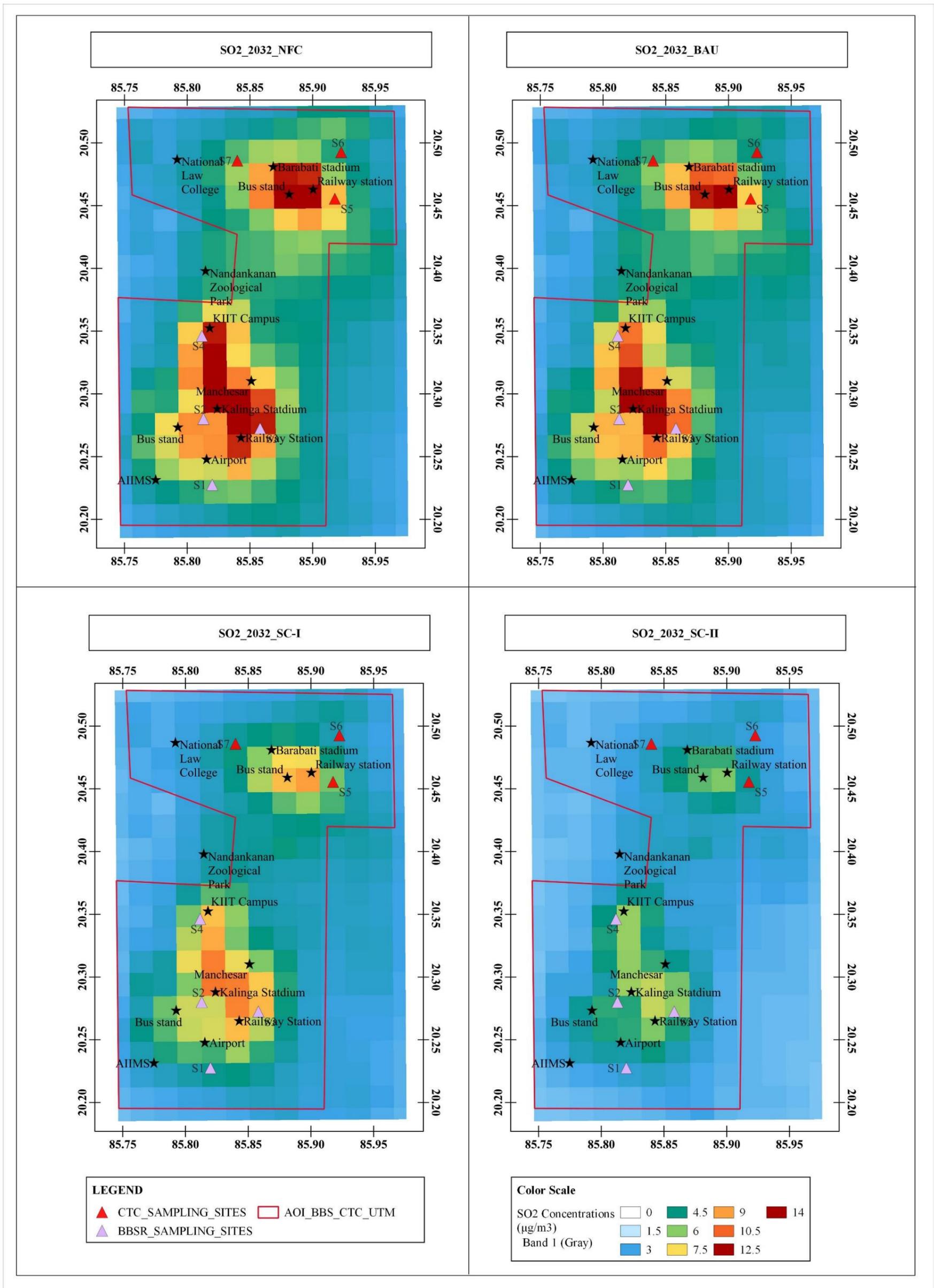


Figure 119 Spatial distribution of annual mean SO<sub>2</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2032 over Bhubaneswar-Cuttack region

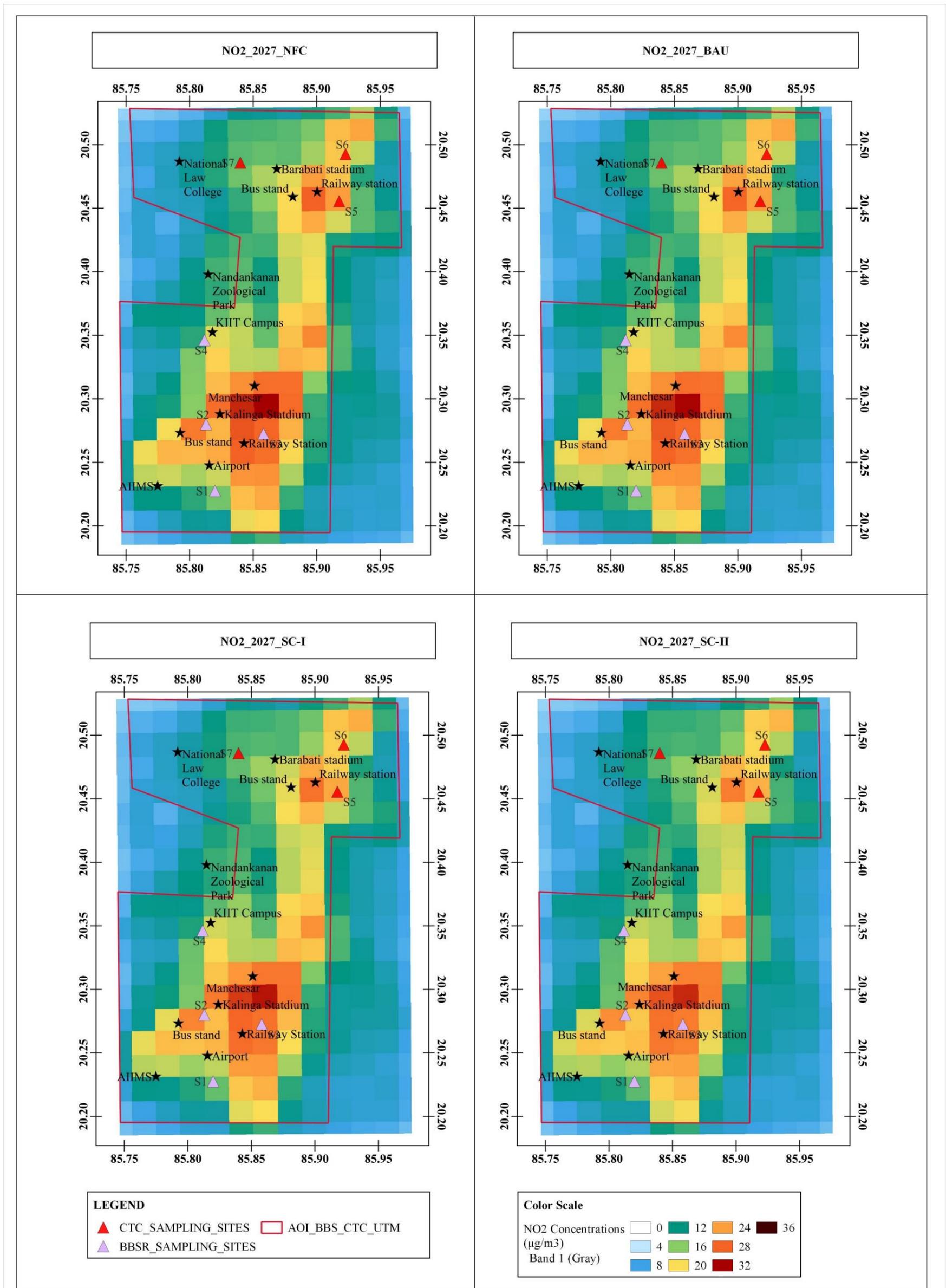


Figure 120 Spatial distribution of annual mean NO<sub>2</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2027 over Bhubaneswar-Cuttack region

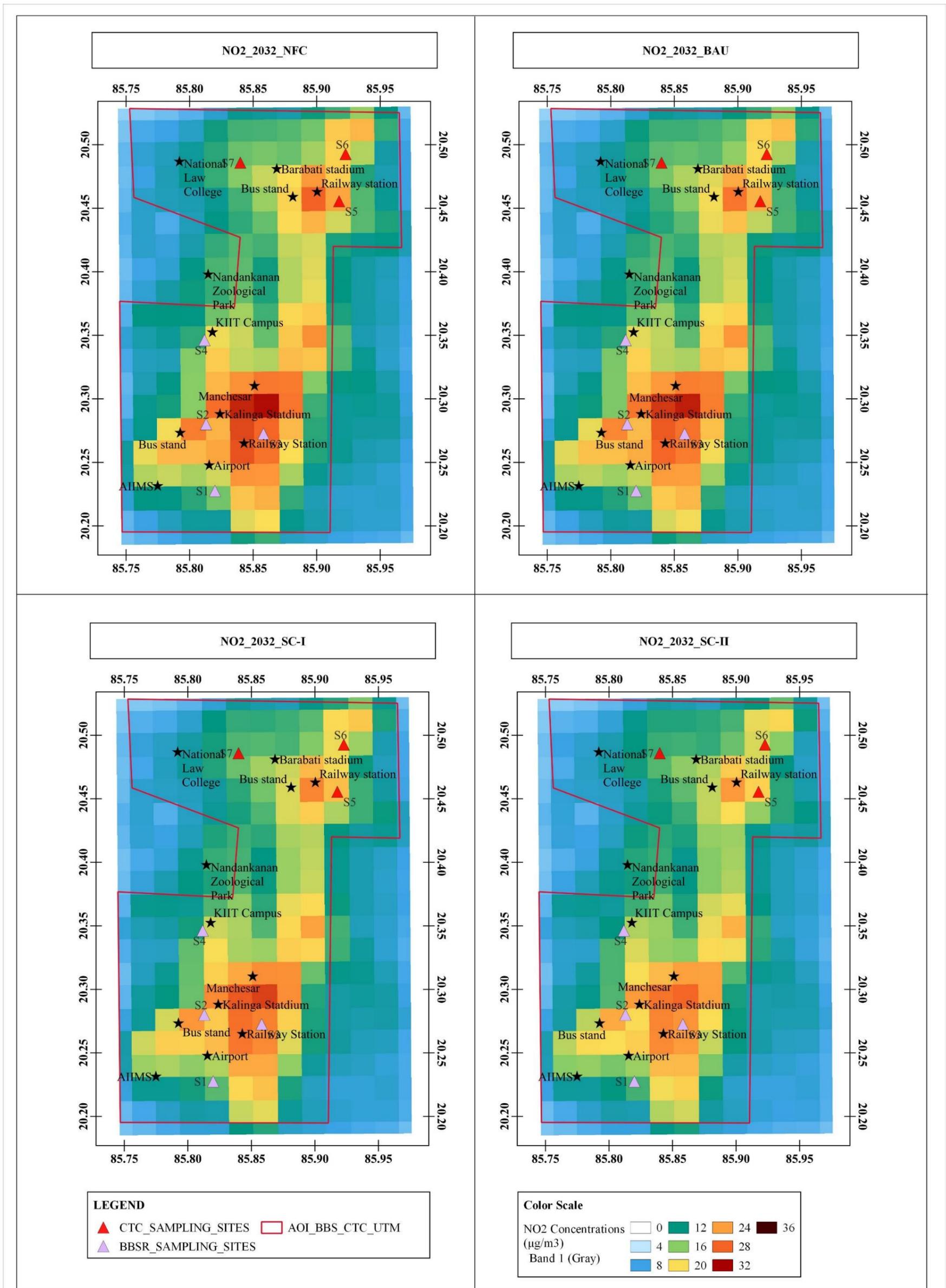


Figure 121 Spatial distribution of annual mean NO<sub>2</sub> concentrations (µg/m<sup>3</sup>) for four scenarios in year 2032 over Bhubaneswar-Cuttack region

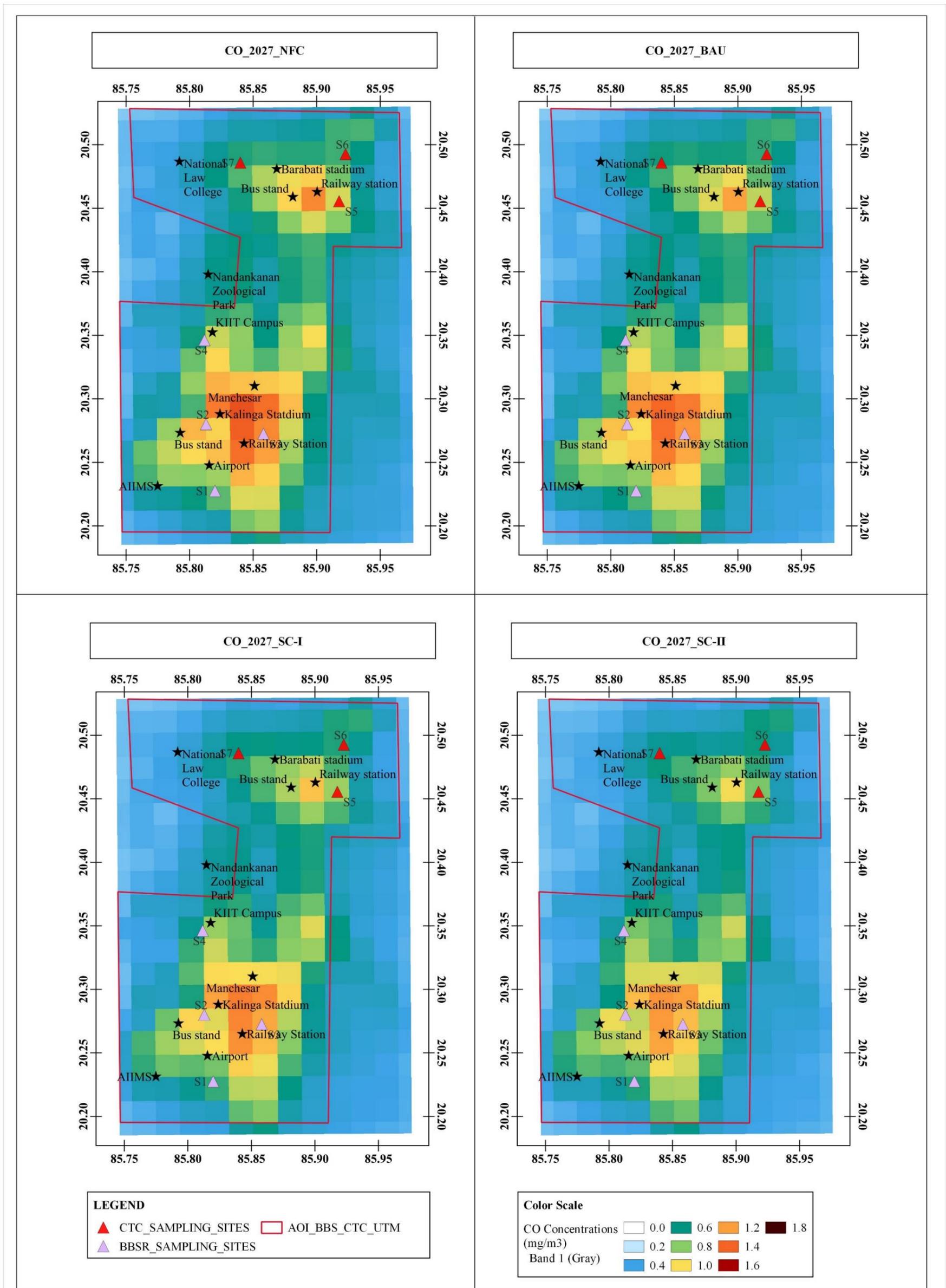


Figure 122 Spatial distribution of annual mean CO concentrations (mg/m<sup>3</sup>) for four scenarios in year 2027 over Bhubaneswar-Cuttack region

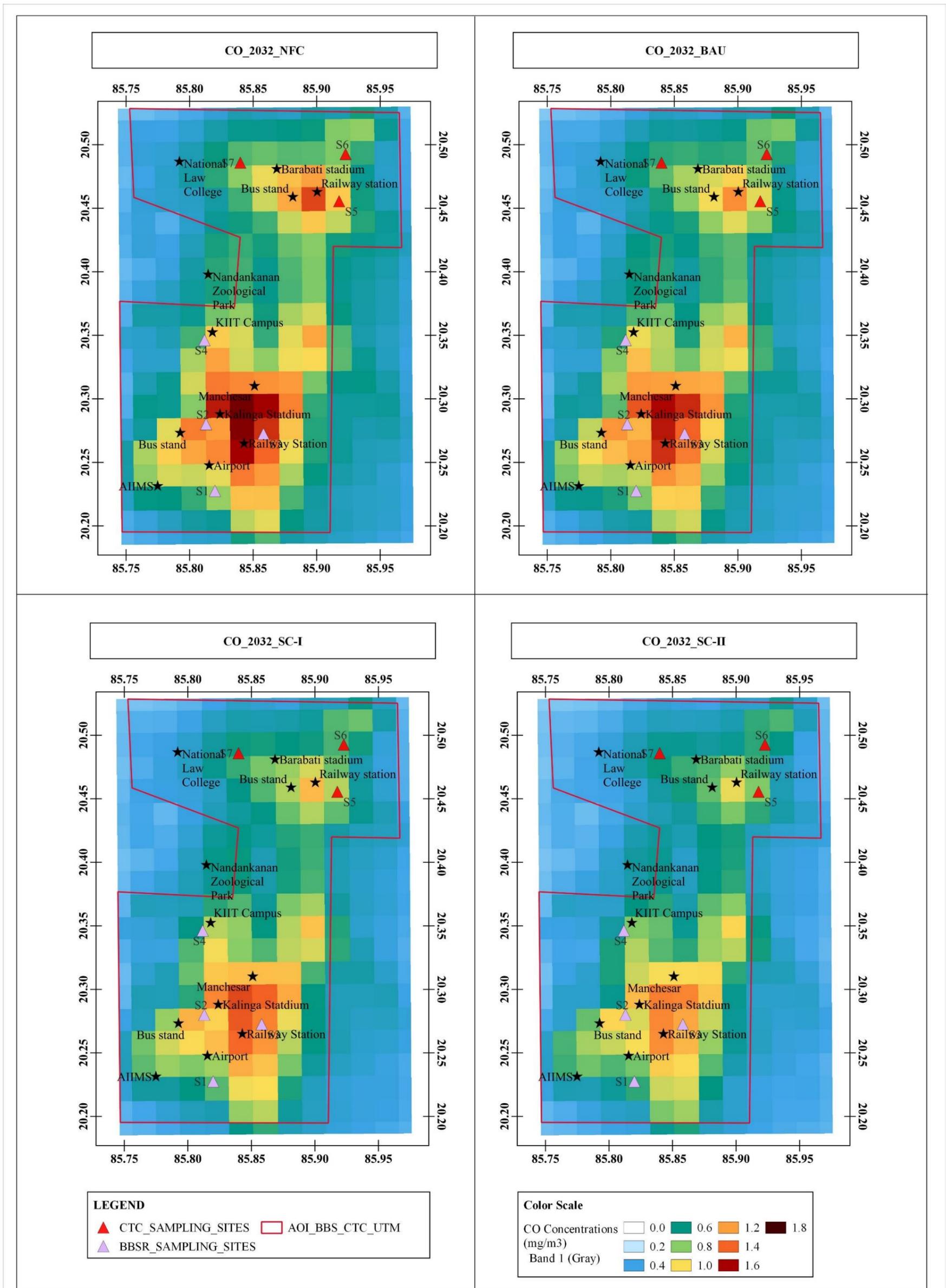


Figure 123 Spatial distribution of annual mean CO concentrations (mg/m<sup>3</sup>) for four scenarios in year 2032 over Bhubaneswar-Cuttack region

This study also assessed location -specific air quality benefits due to implementation of different scenarios in 2027 and 2032. Four representative locations, i.e. ARAI sampling locations, were selected to understand the impact of control measures on air quality. Tables 27 to 30 presents the percentage change in air pollutants annual mean concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at seven selected locations in Bhubaneswar region.

**Table 27 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S1 i.e. Gokhibaba Ashram, Sundarpada sampling location**

Year/Scenario	2027			2032		
	Pollutant	BAU	SC-I	SC-II	BAU	SC-I
PM <sub>10</sub>	-6.3%	-15.8%	-24.4%	-16.3%	-30.4%	-46.8%
PM <sub>2.5</sub>	-5.7%	-15.9%	-24.2%	-14.3%	-28.5%	-43.6%
SO <sub>2</sub>	0.4%	-21.0%	-27.3%	-7.6%	-22.6%	-42.1%
NO <sub>2</sub>	-0.2%	-2.2%	-4.5%	-1.9%	-5.2%	-9.0%
CO	-2.4%	-7.7%	-12.2%	-5.6%	-12.1%	-19.5%

**Table 28 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S2 i.e. OSPCB Head Office, Nayapalli sampling location**

Year/Scenario	2027			2032		
	Pollutant	BAU	SC-I	SC-II	BAU	SC-I
PM <sub>10</sub>	-7.9%	-18.1%	-28.4%	-20.9%	-36.4%	-55.4%
PM <sub>2.5</sub>	-6.9%	-17.2%	-26.5%	-17.3%	-32.6%	-49.5%
SO <sub>2</sub>	-1.6%	-21.6%	-28.3%	-9.5%	-24.7%	-45.2%
NO <sub>2</sub>	-0.4%	-2.3%	-4.7%	-2.3%	-5.8%	-10.0%
CO	-3.0%	-8.2%	-12.9%	-6.5%	-13.7%	-21.8%

**Table 29 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S3 i.e. Office of Chief Instructress Home Economic Training Centre, Jharpada sampling location**

Year/Scenario	2027			2032		
	Pollutant	BAU	SC-I	SC-II	BAU	SC-I
PM <sub>10</sub>	-8.0%	-18.9%	-29.6%	-20.9%	-37.2%	-56.3%
PM <sub>2.5</sub>	-6.9%	-17.5%	-26.9%	-17.0%	-32.8%	-49.1%
SO <sub>2</sub>	-2.5%	-23.8%	-31.6%	-11.7%	-28.8%	-49.1%
NO <sub>2</sub>	-0.6%	-2.9%	-5.7%	-2.5%	-6.7%	-11.4%
CO	-3.2%	-8.8%	-14.1%	-6.8%	-14.4%	-22.8%

**Table 30 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S4 i.e. RO Office, SPCB, Patia sampling location**

Year/Scenario	2027			2032		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM <sub>10</sub>	-7.1%	-17.7%	-26.8%	-17.0%	-33.2%	-48.4%
PM <sub>2.5</sub>	-6.9%	-18.1%	-27.2%	-15.9%	-32.4%	-46.7%
SO <sub>2</sub>	-3.3%	-22.0%	-30.3%	-12.9%	-31.0%	-48.2%
NO <sub>2</sub>	-0.4%	-2.9%	-5.7%	-2.1%	-6.7%	-11.2%
CO	-3.8%	-10.9%	-16.8%	-8.8%	-18.4%	-27.6%

### 5.14.1. Air quality benefits in terms of Air Quality Indices

Air quality index (AQI) is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (Ott, 1978). In this study, a two-step methodology recommended by CPCB is used to calculate daily AQI values (CPCB, 2015). A sub-index (CPCB, 2015; refer Eq. (17)) was first calculated for each pollutant based on its observed and breakpoint concentrations using linear segmented principle. Then the individual sub-indices were aggregated using a maxima function to obtain an overall daily AQI (CPCB, 2015; refer Eq. (18)). The AQI values were then categorized into six different classes: Good (AQI ≤50), Satisfactory (50 < AQI ≤100), Moderate (100 < AQI ≤200), Poor (200 < AQI ≤300), Very poor (300 < AQI ≤400) and Severe (400 < AQI ≤500). The breakpoint concentrations used to calculate the AQI are provided in Annexure-J. In this study, we calculated the AQI using 24-hour mean concentrations of PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub> and SO<sub>2</sub> and maximum 8-hour concentrations of CO for the corresponding day.

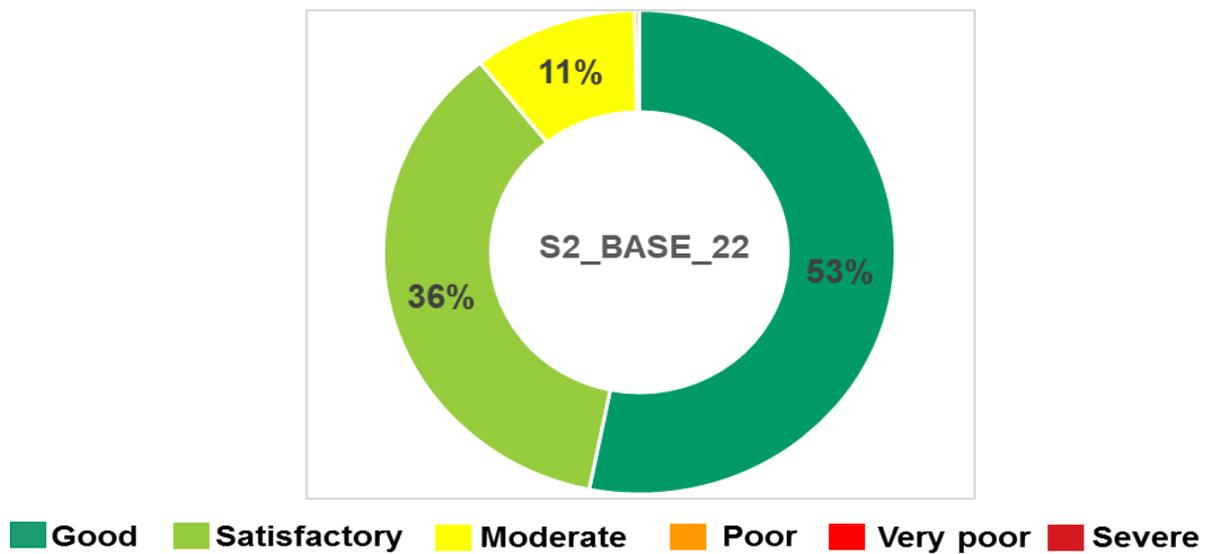
$$I_i = \left[ \left\{ \frac{(I_{HI} - I_{LO})}{(B_{HI} - B_{LO})} \right\} * (C_P - B_{LO}) \right] + I_{LO} \dots \dots \dots (17)$$

where, I<sub>i</sub> = Sub-index for pollutant i, B<sub>HI</sub>= Breakpoint concentration greater or equal to given concentration, B<sub>LO</sub>= Breakpoint concentration smaller or equal to given concentration, I<sub>HI</sub> =AQI value corresponding to B<sub>HI</sub>, I<sub>LO</sub> = AQI value corresponding to B<sub>LO</sub>, and C<sub>P</sub> = Pollutant concentration.

$$I = \max_{i=1,2,3,\dots,n} (I_i) \dots \dots \dots (18)$$

where, I = Overall aggregated AQI, and I<sub>i</sub>= individual sub-indices of each pollutant.

This section discusses the air quality indices (AQI) calculated at representative site i.e. OSPCB Head Office, Nayapalli (S2) for different scenarios in 2027 and 2032 and its implication to short and long-term national air quality goals and future directions. It is important to note that, the AQI values are calculated using the AERMOD estimated pollutant concentrations, only. Fig. 124 shows the distribution of six AQI categories at OSPCB Head Office, Nayapalli (S2) in Bhubaneswar region for modelled concentrations in year 2022, while Fig. 125 and Fig. 126 shows the distribution of AQI categories for different scenarios in 2027 and 2032, respectively.



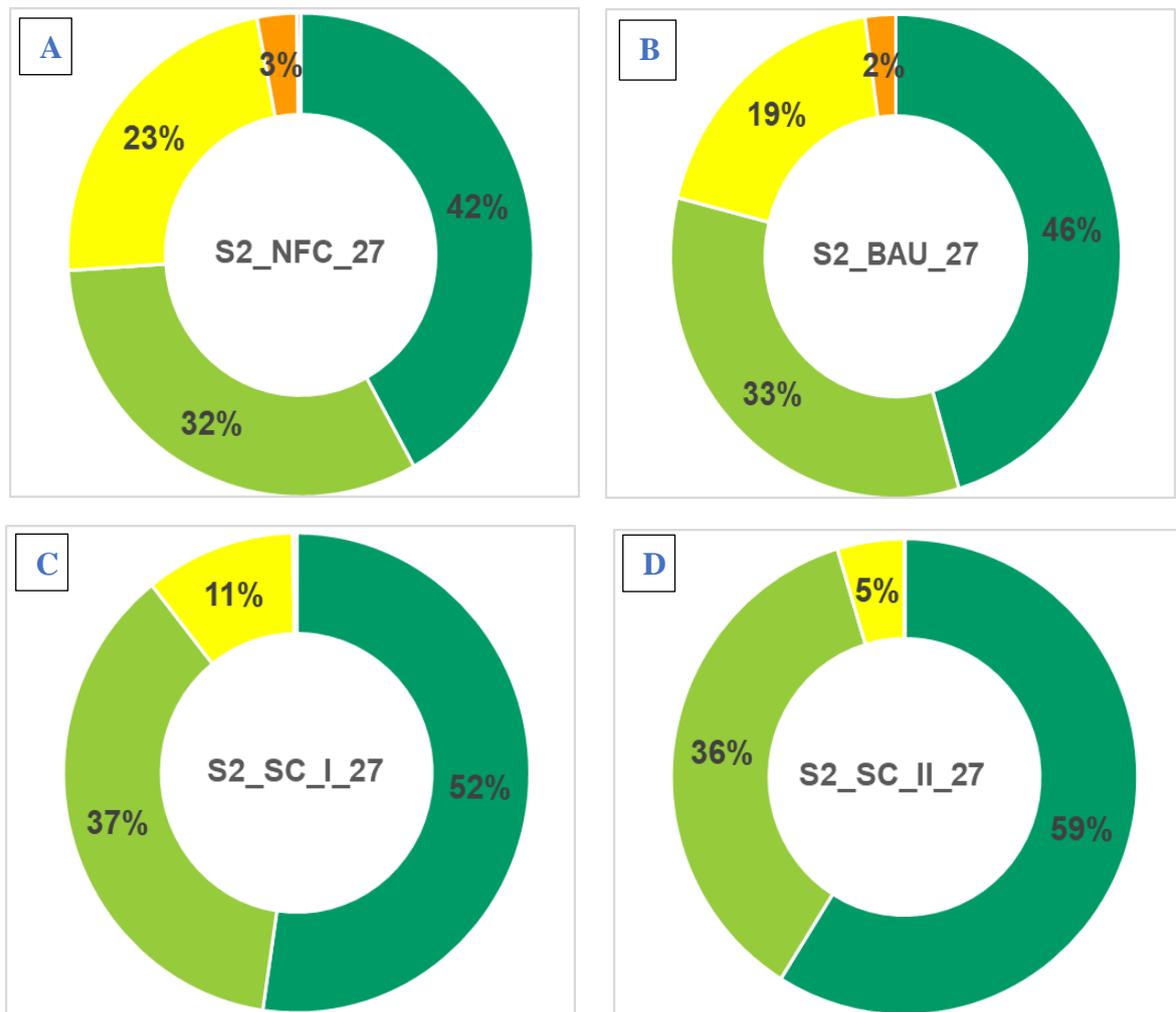
*Figure 124 Distribution of six AQI categories at OSPCB Head Office, Nayapalli (S2) in Bhubaneswar for modelled pollutant concentrations for baseline year 2022*

The AQI at the selected location during baseline scenario in 2022 is mainly driven by PM<sub>10</sub> and on few occasions by PM<sub>2.5</sub>. An examination of modelled AQI for the baseline scenario revealed that air quality index, is mainly distributed in Good (53%), Satisfactory (36%) and Good (10%) classes.

The AQI distribution in NFC scenarios during year 2027 shows degraded air quality compared to baseline year with 42% Good, 32% satisfactory, 23% moderate, and 3% poor days. In year 2032, the air quality situation would further degrade if no further actions are taken. For example, The AQI distribution in NFC scenarios during year 2032 shows degraded air quality compared to baseline year with 30% Good, 30% satisfactory, 33% moderate, 5% poor, and 2% very poor days.

The air quality situation can gradually improve with implementation of proposed control measures. The combined proportion of Good and Satisfactory AQI classes are

estimated to be substantially higher compared to the corresponding do-nothing or NFC scenario. For example, the combined proportion of Good and Satisfactory AQI classes in NFC is 74% and 60% in 2027 and 2032, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 79% and 75% in 2027 and 2032, respectively under BAU scenario, to 89% and 91% in 2027 and 2032, respectively under SC-I, to 95% and 100% in 2027 and 2032, respectively under SC-II scenario. Fig 125 and 126 represents the distribution of AQI categories in four scenarios at OSPCB Head Office, Nayapalli (S2) for years 2027 and 2032, respectively.



**Good Satisfactory Moderate Poor Very poor Severe**

*Figure 125 Distribution of six AQI categories at OSPCB Head Office, Nayapalli (S2) in Bhubaneswar for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2027*

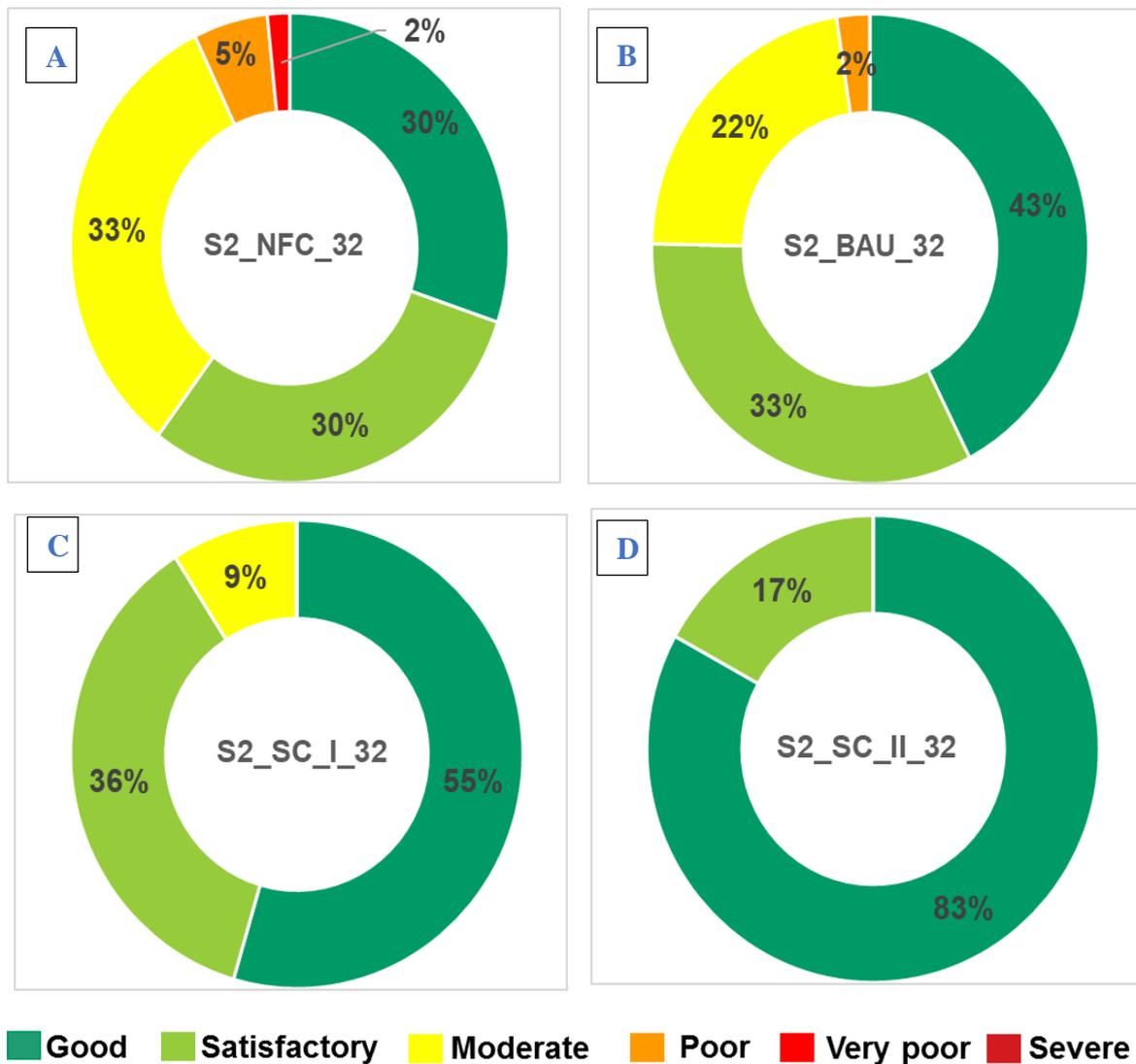


Figure 126 Distribution of six AQI categories at OSPCB Head Office, Nayapalli (S2) in Bhubaneswar for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2032

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Bhubaneswar region as well. These findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level PM concentrations by 40% by the year 2027, as compared to 2017 i.e. base year.

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## Chapter 6: Action Plan

### 6.1. Air Quality Action Plan for Bhubaneswar Region

Table 31 presents the proposed air quality action plan for Bhubaneswar region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

TABLE 31 PROPOSED AIR QUALITY ACTION PLAN FOR BHUBANESWAR REGION

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Transport	<b>A) Management</b>		
	Congestion Management: Identify the hotspot locations of traffic congestion. Introduce traffic actuated signals at such locations. Consider the one-way routes during peak hours at these locations. Also, regulate eateries along the kerbside, especially small ones to avoid traffic congestions.	RTO	Immediate
	Parking Policy: Formulate vehicle parking policy and ensure its effective implementation. Provide parallel parking system along the major roads of the town. Enforce strict action and penalty for vehicles parked in non-parking areas.	Municipal Corporation / RTO	6 months
	Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses), implementation of plan for metro and increase coverage as per plan.	Municipal Corporation	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	Municipal Corporation	1 -2 years
Declare NO-vehicle zones in hot-spots, university / school premises.	Municipal Corporation / University / School	6 months	

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO	Immediate
	Examine existing framework for removing broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.	Municipal Corporation/ Local Govt. Body	6 months
	<b>B) Technology</b>		
	Improve and strengthen PUC program. (SMS based system to alerts, Linking of PUC centres with remote server and elimination of manual intervention in PUC testing, Fitness and calibration audits of PUC centres adopted with defined team for verification, Integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, Linking of PUC certificates with annual vehicle insurance, etc.)	RTO	1 year
	Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Oil Companies/ GAIL / State Government	3 years
	The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	Municipal Corporation/ Local Govt. Body, Government Offices	3 years
	Encouraging EV adoption for personal and commercial vehicles through incentivisation or tax relaxation.	State Government, RTO	3 years
<b>Road Dust</b>	End-to-end paving of roads along with black-topping and maintaining potholes free roads.	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	Municipal Corporation/ Local Govt. Body	Immediate / Continuous

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	Municipal Corporation/ Local Govt. Body	6 months
	All the canals/nallah's side roads should be concrete / brick lined.	Municipal Corporation/ Local Govt. Body	1 year
	Regular cleaning of roads and water spraying to suppress the dust. Remove road dust/silt regularly by using mechanical sweepers.	Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Identify road stretches with high dust generation and use Foggers to suppress the dust.	Municipal Corporation/ Local Govt. Body	6 months
	Greening of traffic corridors, open areas, gardens, community places, schools and housing societies	Municipal Corporation/ Local Govt. Body	1 year
<b>Industries</b>	All potential industries to be implemented with Continuous Emission Monitoring System (CEMS). Ensure regular calibration and working of this system and its online reporting is required.	OSPCB	1 year
	Assess the number of industrial units that are non-compliant and prepare unit/plant wise action plan for time bound compliance.	OSPCB	Immediate and Continuous
	Intensive polluting industries to be restricted from operations within urban zone. Restriction of any new red category industry to open within urban zone.	OSPCB	Immediate
	Strict compliance to be followed on industrial open waste burning.	OSPCB	Immediate
	Control of Fugitive Emissions: <ul style="list-style-type: none"> <li>• Use of hoods and enclosure for all process equipment,</li> <li>• Scrap management programme for the prevention or minimization of waste and other feed materials.</li> <li>• Use of covered or enclosed conveyors and transfer points</li> <li>• Enclosures for emission controls of the charging and tapping operations.</li> </ul>	OSPCB	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
<b>Open Waste Burning</b>	<ul style="list-style-type: none"> <li>Minimising the number of flanges by welding piping connections wherever possible and using appropriate sealing for flanges and valves</li> <li>Use of larger oven chambers and regulation of pressure within oven chambers</li> </ul>		
	Adoption of Cleaner Fuels: <ul style="list-style-type: none"> <li>Cleaner fuel implementation to be encouraged and incentivized.</li> <li>Discourage the fuels with high sulphur content.</li> <li>A favourable taxation and pricing policy for mass adoption.</li> </ul>	OSPCB	1 year
	Ensuring installation/Up-gradation and operation of air pollution control devices in industries	OSPCB	6 months
	Disposal of all non-hazardous wastes into the designated dumping sites	OSPCB	Continuous
	Industry shall prepare plant wise inventory of vents and ensure that it is routed to vapour recovery system followed by flare system, wherever applicable.	OSPCB	6 months
	Regeneration frequency of Adsorption / absorption system / Activated carbon bed should be clearly defined as per the trend data of previous cycles and should be documented.	OSPCB	6 months
	Industry should include a special training module regarding “fugitive emissions and its health impacts on individual and surrounding communities” for its staff, operating personnel & Drivers to spread awareness about risk/hazard associated with spills and leaks of various chemicals.	OSPCB	Continuous
	Bank guarantee should be taken for the compliance of conditions imposed in CTO/CTE for control of Environmental Pollution from industries.	OSPCB	6 months
	Industrial units to install water spraying system of internal roads and washing of tyres of vehicles	OSPCB	6 months
Development of mobile facility/van for continuous ambient air quality monitoring for different localities.	OSPCB	6 months	
<b>Open Waste Burning</b>	Improving door to door waste collection efficiency to 100%.	Municipal Corporation/ Local Govt. Body	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	Municipal Corporation/ Local Govt. Body	Immediate
	Non-recyclable waste with a calorific value of 1,500 kcal or more must not be disposed of into landfills and must be used solely to generate energy	OSPCB, Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Encouraging the reduce, recycle and reuse policy for waste in city	Municipal Corporation/ Local Govt. Body / State Government	Immediate / Continuous
	Organic waste conversion (OWC) units can be installed in the city at a decentralized scale especially in more prominent societies and colonies based on the MSW characteristics of the area.	Municipal Corporation/ Local Govt. Body	1 year
	Effective management of landfill sites through increasing the recycling rate, installing waste to energy conversion plants, restricting illegal waste dumping, proper disposal of hazardous waste, as per Hazardous waste management rule 2016, to prevent greenhouse gas emissions from site	Municipal Corporation/ Local Govt. Body	1 year
	Reduce the VKT of waste collection vehicles with route optimisation technique.	Municipal Corporation/ Local Govt. Body	6 months
<b>Construction</b>	Adoption of Good Construction Practices (GCP) to minimize the waste generation. Promote recycling of materials. Encourage the use of environmentally friendly material. Ensure compliance check for GCP regularly	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate
	Strict enforcement of CPCB guidelines for construction activity such as use of green screens, side covering of digging sites, etc.	Municipal Corporation/ Local Govt. Body / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	Municipal Corporation/ Local Govt. Body	Immediate
	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	3 months
	Develop and implement dust control measures such as site covering, fugitive emission control, installing air pollution controlling devices for all types of construction activities i.e. buildings and infrastructure.	Municipal Corporation/ Local Govt. Body	1 year
	C&D waste should be sent to construction and demolition processing facility only. Strict action against non-compliance of the same on any individual or developers.	Municipal Corporation/ Local Govt. Body	Immediate
	Mandatory use of RMC plants at large construction sites and preparation of guidelines for dust control measures for operation of RMC plants.	Municipal Corporation/ Local Govt. Body / OSPCB	1 Year
<b>DG sets</b>	Ensure uninterrupted electric supply to avoid the use of DG sets, especially in commercial and industrial zones.	State Electricity Board	1 Year
	Curtail use of DG Sets in social events by providing temporary electric connections	Municipal Corporation/ Local Govt. Body / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	Municipal Corporation/ Local Govt. Body	6 months
	Develop the city into a Renewable Energy Hub with a focus on creation of RE Equipment Manufacturing Eco-system as per Odisha Renewable energy policy	Municipal Corporation/ Local Govt. Body / State Government	5 years
	Leverage rooftop solar programme to reduce dependence on DG sets.	Municipal Corporation/ Local Govt. Body	1 year
	Installation of Retrofitted Emission Control Devices (RECD) to diesel generators as per CPCB guidelines	OSPCB	1 year
<b>Residential</b>	Ensure easy availability of affordable cleaner cooking fuels (LPG/ PNG/biogas) for all to achieve 100% LPG adoption.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP/BP, etc.)	1-3 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Expanding coverage of LPG under Pradhan Mantri Ujjwala Yojana (PMUY).	State / Central Government	1-2 years
	Introduce schemes for providing subsidized LPG connections as well as providing means of finance to small tea vendors/hawkers who are using kerosene stoves in order to reduce emissions from burning of kerosene	State / Central Government	1-2 years
	Introduction of improved <i>Chullahs</i> (low emission <i>Chullahs</i> ) in rural areas	Municipal Corporation/ Local Govt. Body, NGOs	1 year
	Encouraging use of electricity for domestic cooking. (for example: Induction cooktops)	Department of Food, Civil Supplies and Consumer Affairs	2 year
	Provide centralized solar based hot water in slum areas to avoid solid fuel usage for water heating purposes	Municipal Corporation/ Local Govt. Body	1 year
Hotel, restaurant and bakeries	Coal and wood-based cooking in restaurants to be shifted to electricity and LPG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1-2 years
	Promoting mini LPG cylinders to small open eateries.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
Brick kilns	Ensure the compliance checking routinely. Provide design specifications for improved kilns.	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate
	Enforce restrictions for the operations of brick kilns in urban zone. Zig-Zag technology to be encouraged and promoted. Ensure the mass adoption of Zig-Zag or improved technology	Municipal Corporation/ Local Govt. Body / OSPCB	1-3 years
	Closure of unauthorized brick kilns, if any.	OSPCB	Immediate
Crematoria	Convert all existing traditional crematoria (wood based) to electric. Installing new electric crematoria as per requirement.	Municipal Corporation/ Local Govt. Body	1 year
Public Awareness	Launch Public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicle, lane discipline, etc.	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
	Encourage the use of public transport for daily commute.	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Education program to create awareness among citizens through various mass media tools, such as local newspapers, local news channels on TV or radio, street plays, social media platforms, citizen engagement events, recording announcements through waste collection vehicle, organizing awareness seminars at the community level	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	Municipal Corporation/ Local Govt. Body	1 year
CAAQMS	Increase the number of air quality monitoring stations, as per applicable Govt. guidelines.	OSPCB	1 -2 year

## **Chapter 7: Future Research Work**

### **7.1. Suggestions for future research work in non-attainment cities**

Although latest available data and methods have been used in this study to identify and quantify the sources of air pollution in non-attainment cities of Odisha, it is suggested to advance the air pollution research to ingest/generate more accurate data and minimize the uncertainties in estimates. Air pollution research is advancing at a rapid pace with development of new and innovative monitoring and analysis techniques, data analysis and modelling tools. Considering the current global trends and situation in non-attainment cities of Odisha, following studies or research areas could be targeted to improve present results and track impact of proposed air action plans.

- **Health impacts analysis of PM using oxidative potential as a metric:** Inhaled PM can directly introduce PM-bound reactive oxygen species (ROS) to the surface of the lung, where they react with and deplete lung-lining fluid antioxidants. The oxidative potential (OP) of ambient particulate matter is a metric commonly used to link the aerosol exposure to its adverse health effects. Research could be taken up to determine the oxidative potential and health risk associated with PM<sub>2.5</sub> particulates in non-attainment cities.
- **Volatile organic compounds (VOCs) and Ozone monitoring:** Unlike primary pollutants, which are emitted directly, tropospheric ozone forms photochemically, involving precursors such as carbon monoxide (CO), volatile organic compounds (VOCs) and oxides of nitrogen (NO<sub>x</sub>), supplemented by transport from the stratosphere (e.g. Crutzen, 1974; Atkinson, 2000; Monks et al., 2015). It can be transported over long distances resulting in enhanced concentrations even in areas remote from the sources of precursors (Cox et al., 1975). It is suggested to augment current monitoring network, to include monitoring of VOCs and Ozone in non-attainment cities.
- **Advanced source apportionment:** Near real time advanced source apportionment using set of state-of-the-art equipment. This can typically include an aerosol chemical speciation monitors (ACSM) to monitor organic aerosols and selected

ions (such as sulfate, nitrate, ammonium, and chlorides); along with a black carbon and a metals analyzer. This set-up can provide high resolution near real time data measurements which can be then followed by PMF analysis to identify sources of air pollution in near real time and on a longer time scale.

- **Improvement in emission inventories:** The present emission inventories could be routinely updated with latest available activity data from secondary data sources and emission factors. With more accurate and high-resolution activity data, uncertainties in emission estimates could be minimized to a great extent.
- **Air quality forecasting systems:** It is very important for decision makers and local administration to understand the levels and possible source contributions in advance. Chemical Transport Modelling based forecasting systems could be developed for non-attainment cities, to forecast air quality in advance. An air pollution decision support system could also be developed to understand the primary contributors and take appropriate actions on ground.

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## **Annexures**

### **Annexure-A: Air Quality Monitoring**

Air quality monitoring is to be done with the speciation samplers to collect PM<sub>10</sub> and PM<sub>2.5</sub> samples. Equipment operational details, working procedure, equipment and sample preparation and maintenance are discussed in detail below.

A-1 Speciation Samplers: Sampling of Particulate Matter PM<sub>10</sub> and PM<sub>2.5</sub> from Ambient Air by Speciation Sampler

#### **1.0 Scope**

This procedure is applicable to air sampling for PM<sub>10</sub> and PM<sub>2.5</sub> using speciation/multi-channel sampler on Teflon / Quartz filter paper.

#### **2.0 Referred Documents**

- 2.1 SOP MLD 055 by California Air Research Board
- 2.2 Model standard operating procedures (SOPs) for sampling and analysis by Central Pollution Control Board, New Delhi

#### **3.0 Significance and Use**

This test procedure is used for collecting Particulate Matter 10 (PM<sub>10</sub>) and Particulate Matter 2.5 (PM<sub>2.5</sub>) from Ambient Air using multichannel speciation samplers.

#### **4.0 Apparatus**

Following apparatus/ instruments will be used: -

- 4.1 Multi-channel/dual channel speciation samplers
- 4.2 Cartridge having Speciation impactor heads and/or impactor channels for PM<sub>10</sub> and PM<sub>2.5</sub> fractions
- 4.3 Filter papers (Teflon/ Quartz)
- 4.4 Proper (blunt) forceps
- 4.5 Labelled Filter paper petri dish for storing Filter paper
- 4.6 Sample Storage Kit

#### **5.0 Chemicals/ consumables:**

- 5.1 High Vacuum Grease

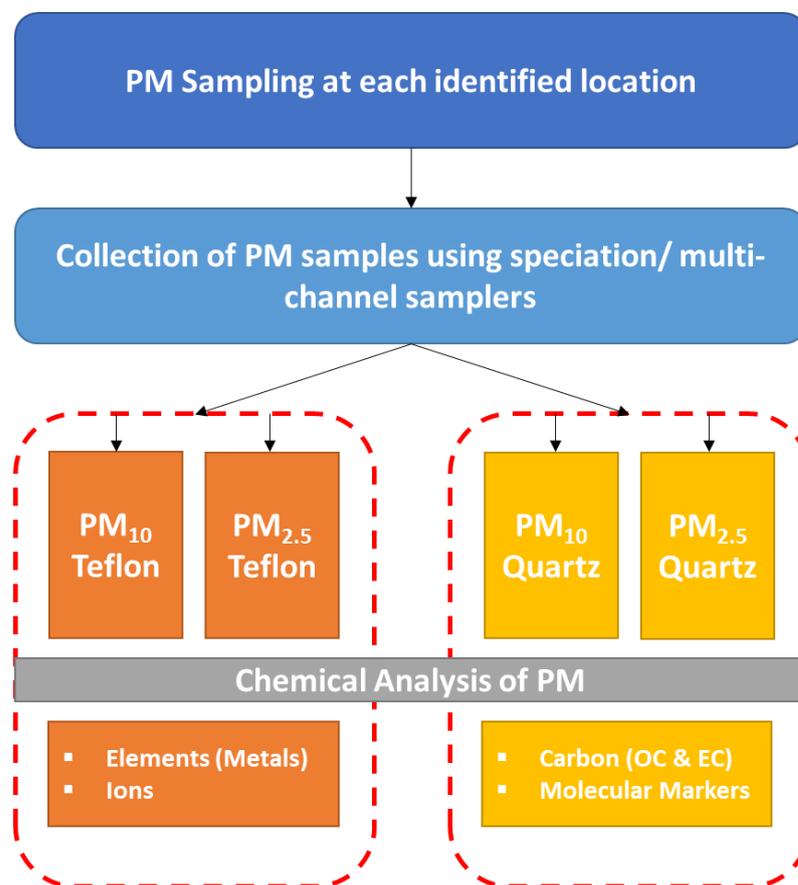
- 5.2 Teflon Filter: PTFE with Polymethyl pentane support ring, Micron size 1  $\mu$ m, 47 mm dia
- 5.3 Quartz Filter paper: Binder free pure Quartz with high flow rate and filtration efficiency, 47 mm dia, Temp stability up to 1100<sup>0</sup>C

**6.0 PPEs TO BE USED:**

Cotton hand gloves, safety shoes

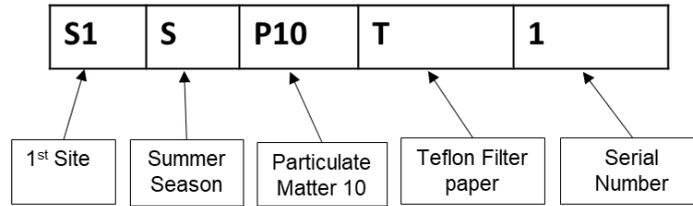
**7.0 Procedure:**

- 7.1 Install speciation sampler as per Manual on stand provided by Manufacturer.



**Fig. A-1: Arrangement of filter papers for multi-channel speciation samplers**

- 7.2 Check Temperature and Humidity sensor connections.
- 7.3 Filter papers are numbered with Site id, Season, PM type, Filter type, serial number.



Similarly, for Winter Season →“W,” PM<sub>2.5</sub> →“P2.5” and Quartz filter paper →“Q”

- 7.4 Select filter paper as per above nomenclature. Visually inspect filter paper for any damages, pinholes or any other collection. If any anomalies are found, then discard filter paper.
- 7.5 Load filter paper in cartridge as per below table:

Channel	PM head	Paper
<b>A</b>	10	Teflon
<b>B</b>	10	Quartz
<b>C</b>	2.5	Teflon
<b>D</b>	2.5	Quartz

- 7.6 Start Speciation sampler as per standard procedure.

## 8.0 Sampling Site photographs



Gokhibaba Ashram



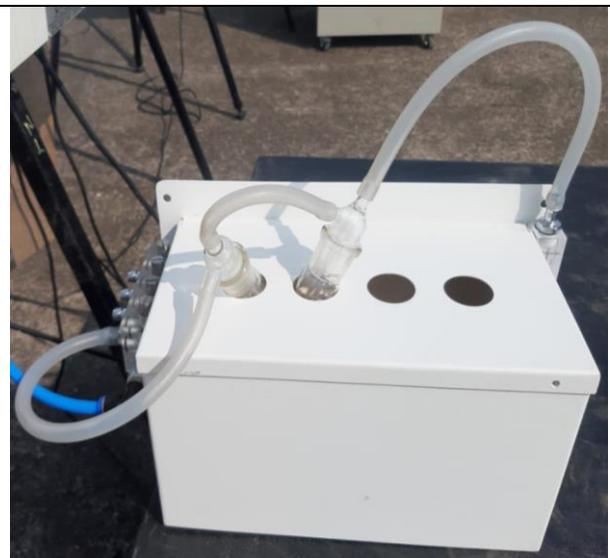
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Training Centre



RO Office, SPCB





## **Annexure-B: Filter sample preparation, handling and weighing**

### **1.0 Scope**

This procedure is applicable for weighing of Teflon Filter paper and Preconditioning of Quartz filter paper used for collecting PM<sub>10</sub> and PM<sub>2.5</sub>

### **2.0 Referred Documents**

- 2.1 Weighing balance Operation Manual
- 2.2 Model Standard Operating Procedures (SOPs) For Sampling and Analysis by Central Pollution Commission Board, New Delhi
- 2.3 Furnace

### **3.0 Significance and Use**

Pre-conditioned blank filter paper is weighed using weighing balance. The weighed filter paper is sent to the field for sampling. The filter paper which has undergone field sampling is received in the laboratory. The received filter paper is kept for conditioning. The conditioned field sample is again weighed using weighing balance and is used for further analysis.

### **4.0 Apparatus**

The designated chemist, engineer will select the appropriate testing reforming master list of instruments.

- 4.1 Weighing balance (Make: Metter Toledo, Model: XP2UV, Mesh Type)
- 4.2 Teflon coated forceps
- 4.3 Millipore Petrislides
- 4.4 Cool kit
- 4.5 Filter Paper used for Sampling:
  - 4.5.1 Teflon Filter paper: 2 µm PTFE 47 mm filter with PP Ring supported (Whatman make)
  - 4.5.2 Quartz Filter paper: Tissue quartz 2500QAT-UP (Pall Make)

### **5.0 Procedure**

#### **5.1 Guidelines for Conditioning of Filter Papers:**

Filter papers selected for different analytical objectives should be conditioned by following steps:

- Inspect all the filter papers for holes or cracks. Reject, if any deformity is found.
- Note down the batch/lot in log sheet.
- Label all the filters following a general lab coding technique, which should be unique to represent a sample.
- Put the marked filters in petri dishes.
- Use always proper (blunt) tweezers/forceps (made of non-reactive material) to handle the filter papers in lab and field as well.
- Prepare a sample-tracking sheet for each filter paper or a batch of filter paper.

## **5.2 Filter Inspection and Stability**

To equilibrate, the filters are transferred from their sealed manufacturer's packaging to a filter-handling container such as a plastic petri-slide. The filters are handled with non-serrated forceps. Lab personnel must wear vinyl gloves as secondary when filters are being prepared for conditioning and weighing. Before any filter is placed in a filter-handling container, it must be inspected for defects. This is done by an examination of the filter on a "light table". A filter must be discarded if any defects are identified. Specific defects to look for are:

- **Pinhole** – A small hole appearing as a distinct and obvious bright point of light when examined over a light table.
- **Separation of ring** – Any separation or lack of seal between the filter and the filter support ring.
- **Chaff or flashing** – Any extra material on the reinforcing ring or on the heat-seal area that would prevent an airtight seal during sampling.
- **Loose materials** – Any extra loose materials or dirt particles on the filter.
- **Discoloration** – Any obvious discoloration that might be evidence of contamination.
- **Other** – A filter with any imperfection not described above, such as irregular surfaces or other results of poor workmanship.

## **6.0 Filter Conditioning**

### **6.1 Pre-firing of Quartz-Fiber Filters**

Quartz-fiber filters absorb organic vapors over time. Blank quartz-fiber filters should be heated for a lot at least three hours at 900°C. One sample of each batch of 100 pre-fired filters is tested for carbon blank levels prior to sampling, and sets of filters with carbon levels exceeding

1 $\mu$ g/cm<sup>3</sup> are re-fired or rejected. All pre-fired filters should be sealed and stored in a freezer prior to preparation for field sampling.

## **6.2 Weighing of Teflon-Membrane Filters before and after sampling**

Gravimetric measurement is the net mass on a filter by weighing the filter before and after sampling with a balance in a temperature and relative humidity-controlled environment as described in SOPs. To minimize particle volatilization and aerosol liquid water bias, PM<sub>2.5</sub> reference methods require that filters be equilibrated for 24 hours at a constant (within  $\pm 5\%$ ) relative humidity between 30% and 40% and at a constant (within  $\pm 2^\circ\text{C}$ ) temperature between 20 $^\circ\text{C}$  and 23 $^\circ\text{C}$ , which is a more stringent requirement than for PM<sub>10</sub> filter equilibration. PM<sub>10</sub> filters are required to be equilibrated at 20% to 45% relative humidity ( $\pm 5\%$ ) and 15 $^\circ\text{C}$  to 30 $^\circ\text{C}$  temperature ( $\pm 3^\circ\text{C}$ ).

These filter equilibrium conditions are intended to minimize the liquid water associated with soluble compounds and to minimize the loss of volatile species. Nominal values of 30% RH and 20 $^\circ\text{C}$  best conserve the particle deposits during sample weighing. Accurate gravimetric analyses require the use of filters with low dielectric constants, high filter integrity, and inertness with respect to absorbing water vapor and other gases.

## **Annexure-C: Analysis of Ions**

### **Method for measurement of Anions and Cations in Particulate matter (PM) samples by Ion Chromatography**

#### **1.0 Scope**

Method for measurement of Anions and Cations in Particulate matter (PM) samples by Ion Chromatography

#### **2.0 Reference Document**

- 2.1 Standard Operating Procedure (SOP) MLD 064 Standard Operating Procedure for the analysis of anions and cations in PM<sub>2.5</sub> speciation samples by Ion Chromatography.
- 2.2 Operation manual of Dionex make Ion Chromatograph.
- 2.3 Methods of Air Sampling and Analysis, 3<sup>rd</sup> Edition by James p. Lodger
- 2.4 Refer file No. CHL/MSDS/74 for Applicable MSDS for proper handling storage use disposal of chemicals for --
  - Sodium Carbonate (Na<sub>2</sub>CO<sub>3</sub>)
  - Sodium Bi-Carbonate (NaHCO<sub>3</sub>)
  - Methane Sulphonic Acid (MSA)

#### **3.0 Summary of Test Procedure**

The method determines the anions and cations present in PM e.g. PM<sub>10</sub> / PM<sub>2.5</sub> dust collected on Teflon filter papers from ambient air which are collected from different sites. The filters are extracted in deionized water by sonicating for one hour, and filtered through 0.22-micron membrane filters. Ion Chromatography using a system comprising of guard column, analytical column, suppressor and a conductivity detector analyzes the final extract. The peak analysis is determined by using Chromeleon software Software Version 7.2.9

- Ions analyzed by Ion chromatograph:
  - Cations: Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>+2</sup>, Ca<sup>+2</sup>

- Anions: F<sup>-</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>

**4.0 Apparatus:**

The test procedure assumes Dionex Ion Chromatographic system. For detailed instructions in the operation of the Dionex IC refer to the operation manual of Dionex.

**4.1 Dionex Ion Chromatographic system comprised of following modular units, one for Anions and Cations:**

- Isocratic pump
- Guard and Analytical Column
- Suppressor
- Conductivity detector
- Automated Sampler

**4.2 IC Operating Conditions:**

<b>Sample loop volume:</b>	<b>25 µl for anions and cations</b>
<b>Analytical Column:</b>	
Anions	Dionex Ion Pac AS23 Analytical column
Cations	Ion Pac SCS1 Separator column
<b>Guard Column:</b>	
Anions	Dionex Ion Pac AG23 guard column
Cations	Dionex Ion Pac SCG1 guard column
<b>Eluent solutions:</b>	
Anions	4.5 mM carbonate / 0.8 mM bicarbonate
<b>Eluent solutions:</b>	3.5 mM Methane Sulphonic Acid (MSA)
Cations	
<b>Eluent flow rates:</b>	
Anions	1.5ml/min
Cations	1.0ml/min

<b>Sample loop volume:</b>	<b>25 µl for anions and cations</b>
Acquisition Software	Chromeleon Software Version 7.2.9
Pressure	Max. 5000 Psi
Suppressor for anion	AERS type 600 (4mm) suppressor
Suppressor for Cation	CERS type 600 (4mm) suppressor
<b>Analysis Time:</b>	
Anion	20min
Cation	35min

#### 4.3 Other Equipment:

- Ultrasonicator
- Analytical balance

#### 4.4 Glassware:

- Volumetric flasks: 50, 100, 1000 ml sizes
- Polyethylene storage bottles
- Beakers: 100 ml size
- Thermoscientific Autosampler Vials with caps
- Gloves disposable
- Micropipettes: Ranging from 10 µl to 1000 µl

#### 5.0 Reagents:

(All reagents should confirm to ACS specifications for reagent grade materials unless otherwise specified.)

- Sodium Carbonate (Na<sub>2</sub>CO<sub>3</sub>)
- Sodium Bi-Carbonate (NaHCO<sub>3</sub>)
- Methane Sulphonic Acid (MSA)
- Milli-Q Grade ASTM type 1 deionized water (18.2 Mega Ohm cm<sup>-1</sup>)
- Anion Standard (F<sup>-</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>)
- Cation Standard (Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>+2</sup>, Ca<sup>+2</sup>)

#### 6.0 Procedure:

Preparation of Eluents-

Stock eluents are prepared in ultrapure water. The following table lists the amounts of each chemical used to make one batch of stock solution:

	<b>Chemicals</b>	<b>Amount of Chemicals</b>
Anion Eluent	Sodium carbonate and Sodium bicarbonate	4.5 mM (0.4770gm/lit) and 0.8 mM (0.0672gm/lit)
	Nanopure Water	Type 1 grade (Qty req as above)
Cation Eluent	Methane Sulphonic Acid	30 mM (2000 µl/lit)
	Nanopure Water	Type 1 grade (Qty req as above)

	<b>Chemicals</b>	<b>Amount of Chemicals</b>
<i>Anion Eluent</i>	Sodium carbonate and Sodium bicarbonate	4.5 mM (0.4770gm/lit) and 0.8 mM (0.0672gm/lit)
	Nanopure Water	Type 1 grade (Qty req as above)
<i>Cation Eluent</i>	Methane Sulphonic Acid	3.8 mM (253.3 µl/lit)
	Nanopure Water	Type 1 grade (Qty req as above)

- 6.1** Anion Eluent – Weigh Sodium carbonate and Sodium bicarbonate as per quantity given in the above table and transfer into a 1 lit volumetric flask containing about 500 ml of Milli-Q water. Mix the contents and sonicate to dissolve. Once all chemicals have dissolved make up the volume to 1 lit. Sonicate the mobile phase for about 5 minutes. Always use clean and oven dried glassware for eluent preparation.
- 6.2** Cation Eluent – Pipette 2000 µl of MSA and transfer into a 1 lit volumetric flask containing about 500 ml of Milli-Q water. Mix it and make up the volume to 1 lit. Sonicate the mobile phase for about 5 minutes. Always use clean and oven dried glassware for eluent preparation.
- 6.3** Preparation of Anion and Cation Calibration Standards –Multi-point Calibration Curve of different concentrations ranging from 1 ppm to 10ppm are selected which includes 1, 3, 5 and 10 ppm. All the dilutions are made in Milli-Q grade deionized water.

**6.4** The concentration levels that have to be selected for Multi-point Calibrations are to be repeated for minimum three times before using for Calibration. Relative Standard Deviation (RSD) for each anion should be below 3%. In order to accept the Calibration Curve, Correlation Coefficient should always be greater than or equals to 0.990. Otherwise Calibration standards should be re-analyzed

**6.5 Filter Analysis:**

Filter papers are stored in a controlled temperature and humidity conditions. Following steps were followed before taking samples for analysis:

- Prepare a work list of samples to be analyzed containing details of date of collection of samples, site identification, duration of sample collection and any other observations interfering the analysis.
- Label the samples properly with above details and should be numbered.
- Always consider one field blank and one laboratory blank for each set of samples.
- Prepare sequence for the analytical run that begins with the calibration standards in order of increasing concentration, followed by water blank and sample. Follow this list including at least 10 % duplicate and after each set of analysis another check standard. At the end of the samples field blank and laboratory blank are analyzed.
- Cut the exposed filter into small pieces with cutter and place it in a 50 ml beaker. Add 30 ml deionized water into it. Also take one blank filter (unexposed to air) and follow same procedure.
- Place all the beakers in ultrasonicator bath for 60 min. After sonication remove them from bath and wipe the bottom of beaker with towel or tissue paper.
- After sonication shake the samples and stir the contents in the beaker.
- Filter the samples now through 0.22-micron size membrane (Pall Gelman make or equivalent) filters using vacuum extraction assembly. Ensure that the extract is clear and transparent after filtration. Make up the volume of sample up to 50 to 100 ml depending upon the analysis requirement. If concentration of an analyte is beyond the range of calibration, dilute the sample accordingly. The sample is now ready for analysis on Ion Chromatograph.

- Transfer the contents of sample into autosampler vials and cap each vial. Run the sequence of samples as mentioned above and operate the IC Software for analysis of anions and cations at above instrumental conditions. The results are given in ppm or mg / lit.

## **7.0 Calculations:**

### **7.1 Calculation of Volume of Air Sampled**

$$V = QT$$

V = Volume of air sampled in m<sup>3</sup>

Q = Mean flow rate in m<sup>3</sup>/minute

T = Total sampling time in minute

### **7.2 Calculation of Anions and Cations in PM in Ambient Air**

$$\text{Concentration of Ion } \mu\text{g/ m}^3 = [(C \times V_1) - B] / (V \times F)$$

Where,

C= concentration of ( $\mu\text{g}$  or mg of Ion / ml) in the aliquot

V<sub>1</sub> = Volume of aliquot (ml)

B = total  $\mu\text{g}$  or mg of Ion in blank

F = Fraction of total sample in the aliquot used for measurement

V = Volume of air sampled

## **Report**

Report Concentration of desired anions and cations in mg and percentage (%) and micrograms ( $\mu\text{g}$ ) per cubic meter (m<sup>3</sup>) of ambient particulate matter.

## 9.0 Calibration Records:

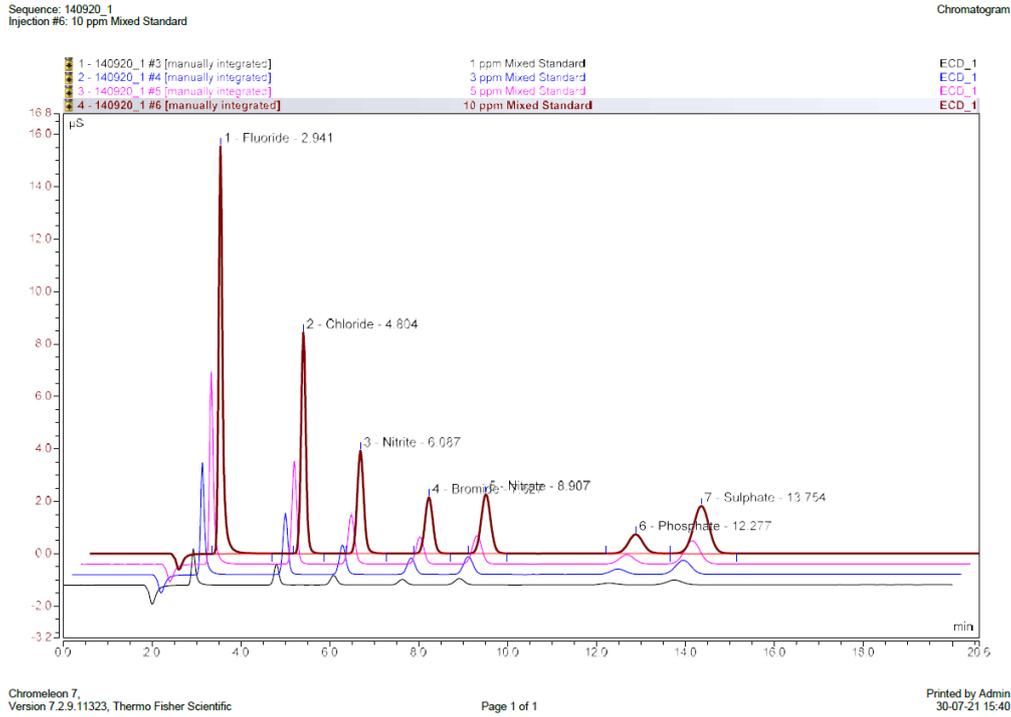


Fig. C-1: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Anion

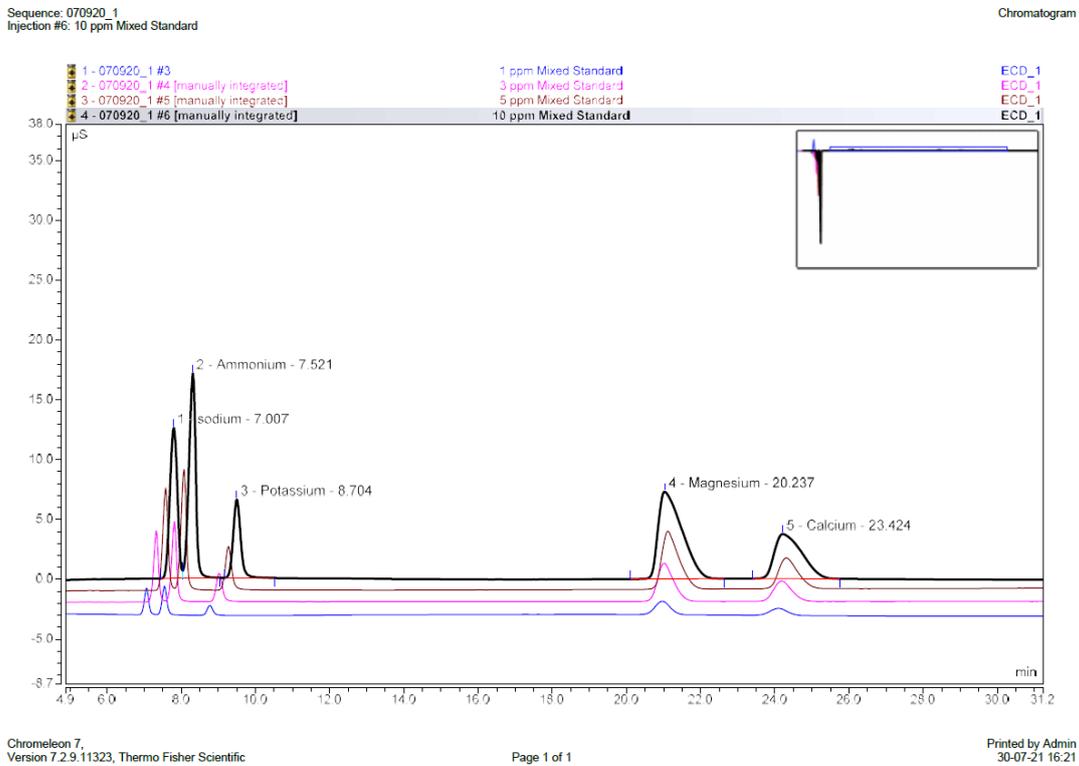


Fig. C-2: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Cation

## **Annexure-D: Analysis of Elements**

### **Determination of Metal Content in Particulate Matter (PM) Collected on Teflon Filter Paper by X-Ray Fluorescence Spectrometer**

#### **1.0 Scope**

- 1.1 This procedure is applicable to analysis of particulate matter (PM) collected on Teflon filter papers from ambient air.

#### **2.0 Reference Document**

- 2.1 Compendium Method IO-3.3, Determination of metals in ambient particulate matter using X-Ray Fluorescence (XRF) Spectroscopy, US EPA, June 1999

#### **3.0 Summary of Test Procedure**

Elemental Analysis of Air Particulate by Energy Dispersive X-ray Fluorescence (EDXRF). This method applies to the analysis of ambient air particulate collected on 47mm diameter Teflon Filters.

This method describes quantitative determination of elements in ambient air particulate collected on Teflon membrane filters. The elements that are determined by this method include many of the elements with atomic numbers 11 (Na) to 82 (Pb). (Note: both Na and Mg are analysed but measured as ION only).

The method assumes that the particulate is collected as a surface deposit on top of the filter media, that the particulate loading level is less than approximately  $100 \mu\text{g}/\text{cm}^2$ .

An X-ray source removes electrons from the inner shells of atoms by exciting the atoms to energy states above the stable configuration. As electrons move to refill the ground state energy levels, the atomic system maintains its fundamental energy balance by emission of electromagnetic radiation. The emitted radiation is an x-ray whose energy is characteristic of the excited element. The samples are quantitatively analyzed by counting the number of

observed x-rays over a set period, as compared with the number of fluoresced x-rays from similarly analyzed standards.

- Elements analysed by XRF: Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb

#### **4.0 Apparatus**

X-ray Fluorescence Spectrometer

#### **5.0 Certified Reference Material**

5.1 Single-element Thin-film calibration standards from Micromatter

#### **6.0 Procedure**

- 6.1 Switch on the equipment as per Work Instruction No. ERL/WI/106.
- 6.2 Double click on the “PCEDX Pro” icon on the desktop for qualitative or quantitative analysis
- 6.3 The “Start-up” and “Analysis” windows will open. From the “Start-up” window, a message “Instrument is not initialized” will pop up. Now, click on “Initialize”. Initialization will take 15 mins.
- 6.4 Click in sample schedule on analysis window, select instrument calibration and click on “OK”.
- 6.5 Place the energy check sample over the beam window and click on “Start” from the Analysis window. After energy check analysis is completed remove the energy check sample.
- 6.6 For the analysis of sample, place the sample on the beam window. Click on “Sample Schedule”. Click on “Sample Registration”. Click on “Analytical group” from the “Analysis” tab and select the appropriate analytical group for air as per the sample.
- 6.7 Give proper name and position where the sample is to be placed and click on “Apply”.

- 6.8 Click on “Start” from “Analysis” window. On completion of analysis, Results window with Pop up.
- 6.9 Take out the sample from the sample chamber.
- 6.10 Similarly carry out the analysis in Helium by selecting appropriate “Analytical group” for helium by following clauses 7.5 to 7.8. Take out the sample from the sample chamber.
- 6.11 To generate the report of sample, click on “Data” from the main menu and select the sample. Click on “File” then click on “Create Ex Report”, select the format as Excel and click on “Create”. Click on “Option” and select “Enable this content”. Now, click on “OK”. Save the file in the desired location. The report is in the form of excel with the elements identified and its concentration in  $\mu\text{g}/\text{cm}^2$ .
- 6.12 Periodically carry out the analysis of Micrometer XRF Calibration Standards. The obtained value of concentration should be within  $\pm 5$  % of specified value.
- 6.12.1 Record the result of the calibration in the form of enclosed format.

### **6.13 Calibration:**

- 6.13.1 The Micromatter thin film standard material and sample under test are analysed by XRF in the same run. The equipment is said to be in a state of acceptable valid calibration if the acceptance criteria (10% deviation) is met.

## **7.0 Calculations**

- 7.1 Concentration of the elements in the sample are calculated by the software in  $\mu\text{g}/\text{cm}^2$ .
- 7.2 Results are converted to  $\mu\text{g}/\text{m}^3$  by using exposed area of filter and volume of air sampled.

## **8.0 Reporting**

- a) Report the result in the desired unit e.g.  $\mu\text{g}/\text{cm}^2$  up to 2 decimal places.

## **Annexure-E: Carbon Analysis**

### **Analysis of Organic Carbon (OC) and Elemental Carbon (EC) in Particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>)**

#### **1.0 Scope**

This procedure describes the analysis of exposed quartz micro fiber filters for organic carbon (OC) and elemental carbon (EC) in Particulate matter (PM) samples using a Desert Research Institute (DRI) Multi-Wavelength Thermal/Optical Carbon Analyzer

#### **2.0 Referred Documents**

2.1 Standard Operating Procedure (SOP) MLD 065 Standard Operating Procedure for the analysis of Organic and Elemental Carbon in Particulate matter (PM) samples by using DRI Model 2015 series 2 Multi-Wavelength Thermal/Optical Carbon Analyzer.

2.2 Operation manual of DRI make Multi-Wavelength Thermal/Optical Carbon Analyzer.

#### **3.0 Summary of test Procedure**

The operation of the DRI Model 2001 Thermal/Optical Carbon Analyzer is based on the preferential oxidation of organic carbon (OC) compounds and elemental carbon (EC) at different temperatures. The principle function of Modulated diode lasers is to measure the reflectance from, and transmittance through, each filter at wavelengths 405, 445, 532, 635, 780, 808 and 980nm.

#### **4.0 Apparatus**

The designated chemist, engineer will select the appropriate testing reforming master list of instruments.

4.1 Desert Research Institute (DRI) Model 2015 Thermal Optical Carbon Analyzer (AML/ INST/ 149) System with computer.

4.2 Stainless steel punching tool: 5/16-inch diameter, 0.5 cm<sup>2</sup> nominal area.

4.3 Syringes: Hamilton Gas-Tight 1000 µl syringe for calibration injections; 25 µl syringe for carbonate analysis and for analyzer calibration.

- 4.4 Flat-tip tweezers.
- 4.5 Flat glass plate.
- 4.6 Tissue paper
- 4.7 Glassware
- 4.8 **Gases:** All gases are required of high purity grade

Sr. No.	Name of the gas	Regulated pressure (psi)	Purpose
1.	Helium	15-40	As a carrier gas
2.	10 % O <sub>2</sub> in helium	15	As a carrier gas
3.	Zero air	100	For pneumatic activation
4.	5% methane in He	10	Internal Calibration
5.	5% CO <sub>2</sub> in He	10	Calibration

## 5.0 Chemicals:

- 5.1 Potassium Hydrogen Phthalate (KHP)
- 5.2 Sucrose
- 5.4 Ultrapure ASTM type 1 deionized water (>16 Mega Ohm-cm).

## 6.0 Procedure

6.1 **Analyzer start-up** (When the analyzer is started up for the first time, or after an extended period of non-operation):

- Check the gases for their pressures/settings.
- Start all the gases on panel
- **Start PC only.**
- Put on Analyzer (Switch is on the rear side of the analyzer.)
- Wait for 3.5 min and then start EC OC application software carbon 2015.
- Go to calibration control from DRI Model 2015 Thermal optical carbon analyzer page

- Heat Oxygenator to 900°C with an increment of 100°C withhold time 30 minutes at each increment.
- When system stabilization is achieved then perform the leak check test. For daily routine operation, start the operation with leak check test onwards.

## **6.2 Leak Check test**

- Close sample back valve – it becomes red. (All the valves should be off i.e. red)
- Click on Leak test Valve. System pressure should be increased by at least 1 psi from the previous valve
- After the leak check test is PASS, click on Leak test to Turn it OFF
- Click on Back valve it should be Green

## **6.3 Oven Baking**

- Oven Baking is performed after Leak Check is passed
- Select “Analysis” from the “Main” submenu of the Welcome form. This will initiate the analysis protocol.
- Select BAKE protocol
- Enter the Sample ID number Enter the Run #, Punch area and Deposit area for the filter being analyzed. Punch area and Deposit area should be “1”. Enter technician initials in the “Tech initials” field.
- Click “OK” on the analysis “Setup” screen.
- Repeat until the system is clean. Sample runs or calibrations may then begin.
- System blanks are run after the oven bake.

## **6.4 Auto-calibration**

- Auto-calibration is performed after system bake
- Select “Analysis” from the “Main” submenu of the Welcome form. This will initiate the analysis protocol.
- Select Bake Protocol from analysis window.
- In the analysis “Setup” form, enter “Sample” for the Type.
- Enter the Sample ID number as “AutoCalib\_Date”, Enter the Run #, Punch area and Deposit area for the filter being analyzed. Punch area and Deposit area should be “1”. Enter technician initials in the “Tech initials” field.
- Click “OK” on the analysis “Setup” screen.

- After the run time is over, computer will prompt the calibration check result.
- Do not proceed to sample analysis unless calibration is established or confirmed. There should not be more than 10% difference in three peak areas of calibration.

## **6.5 Sample analysis**

- Note down the sample details.
- Examine the filter visually and note any non-uniformity or unusual deposit. Place the filter on the flat glass plate and remove a sample punch using punching tool.
- Select “Analysis” from the “Main” submenu of the Welcome form. This will initiate the analysis protocol.
- In analysis window, select IMPOVE A protocol
- Enter the Sample ID number, Enter the Run #, Punch area and Deposit area for the filter being analyzed. Enter technician initials in the “Tech initials” field.
- Click “OK” on the analysis “Setup” screen. Computer will prompt to load the filter punch. But when prompted to load filter punch,
- Load the punch in boat and Click “OK” to start analysis.

## **6.6 Filter blank**

- Filter blank analysis is performed similar to sample analysis with pre-baked blank filter paper punch loaded instead of sample punch.
- Pre-baking of blank filter paper is carried out by heating the blank filter paper in furnace at 900°C for 4 hrs using porcelain dishes and preserved in dessicator.

## **6.7 Calibration**

- The instrument is calibrated every six months or the internal calibration gas cylinder is changed, whichever is earlier. 5% CO<sub>2</sub> in He, 5% CH<sub>4</sub> in He and KHP are used for calibration. 5% CH<sub>4</sub> in He is also used for end of run calibration automatically injected by the instrument.
- 5% CO<sub>2</sub> in He is injected in the volume 100 ul, 200 ul, 500 ul, 700 ul and 1000 ul.
- 5% CH<sub>4</sub> in He is injected in the volume 100 ul, 200 ul, 500 ul, 700 ul and 1000 ul.

- The gas standard concentrations are corrected for temperature and pressure at laboratory conditions using ideal gas law and certified percent of gas in cylinder.
- The injection peak counts divided by calibration peak counts is calculated and slope is determined by plotting calculated carbon in ug vs. injection peak area/calibration peak area. The line is forced through zero.
- The slope value determined from calibration standards is entered into *carbon.par* table

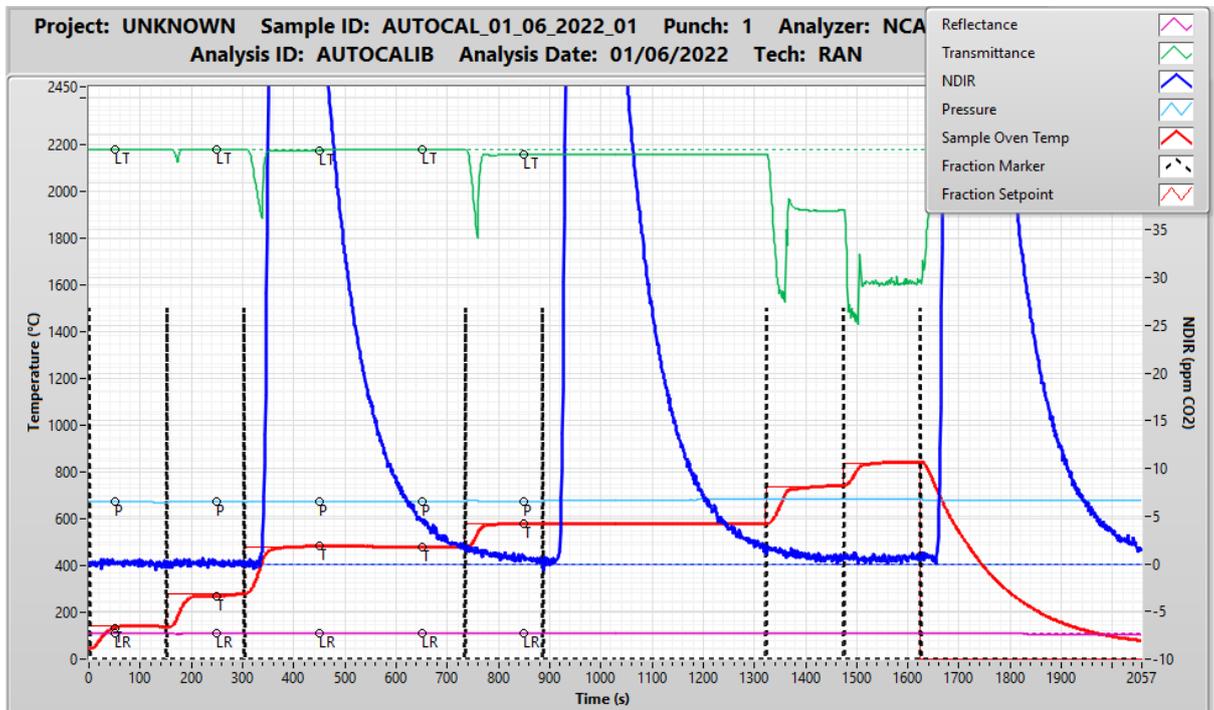
## 7.0 Calculations

The conversion of integrated peak counts to  $\mu\text{g}$  of carbon for each peak in the thermogram is performed by the computer at the end of the analysis program based on analysis result, punch area, deposit area, internal calibration peak area.

## 8.0 Reporting

Report Concentration of Organic carbon fractions (OC1, OC2, OC3 and OC4) and Elemental Carbon Fractions (EC1, EC2 and EC3) in the PM.

## 9.0 Calibration Graphs



**Fig. E-1: Typical example of Auto-calibration run taken on every day before actual testing starts**

## Annexure-F: QA/QC

### OUTLINES OF FIELD AND LABORATORY PERFORMANCE AUDITS

Sr. No.	Parameter	Standard Ref. Method	Test procedure/ SOP	Analytical technique/ method	Calibration standard details	Performance test method	Perform. test frequency	Calibration periodicity	Primary standard
1	Sample flow	ERT/DRI modified	TP-AQM-Samp-AML	Instrumex samplers	Calibrated rotameter	Calibrated rotameter	Once a day	At the beginning or when the performance tests out of specifications	Certified root meter
2	PM <sub>10</sub>	CARB/MLD NO.031	TP-AQM-PM <sub>10</sub> -AML	Gravimetric	NBS Class M standards weights	NBS Class M standards weights	Once a day	At the beginning of weighing session	NBS Class M standards weights
3	PM <sub>2.5</sub>	CARB/MLD NO.055	TP-AQM-PM <sub>2.5</sub> -AML	Gravimetric	NBS Class M standards weights	NBS Class M standards weights	Once a day	At the beginning of weighing session	NBS Class M standards weights
4	Elements	Method IO – 3.3 for XRF CARB	TP-AQM-Elements-AML	Energy dispersive -X-Ray fluorescence (ED-XRF)	Micromatter thin film standards	Replicate thin film standard	1/10th sample	Once in two months or when the performance test not met	Micromatter thin film standards
5	Ions	CARB/MLD NO.064	TP-155-AML	Ion Chromatograph with conductivity detector	NIST Traceable MERCK make Certipur Standards	Standard solution	1/10th sample	At the beginning of each run	Certified NIST traceable standards
6	EC/OC	CARB/MLD NO.065	TP-156-AML	Thermal optical reflectance carbon analyzer	Methane, CO <sub>2</sub> gas, and ACS-certified KHP	Replicate methane gas run	1/10th sample	Once in two months or when performance test not met	ACS certified chemicals

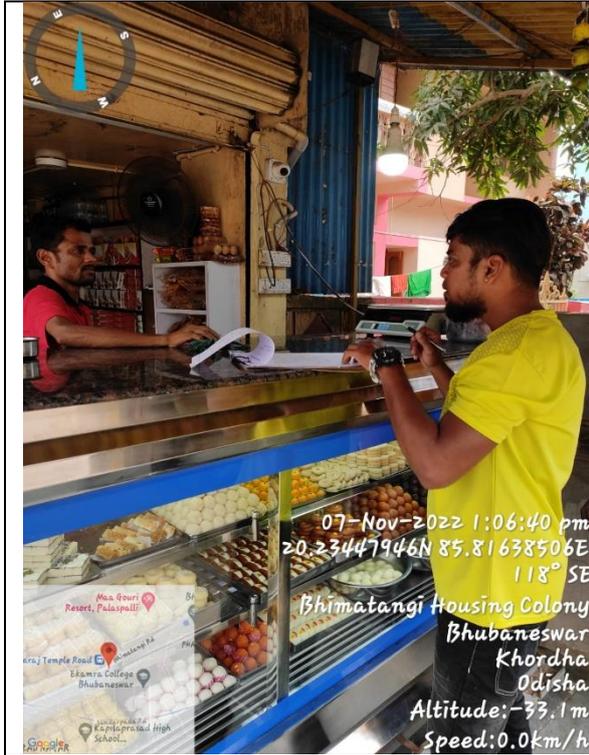
## **Annexure-G: Emission Inventory Activities**



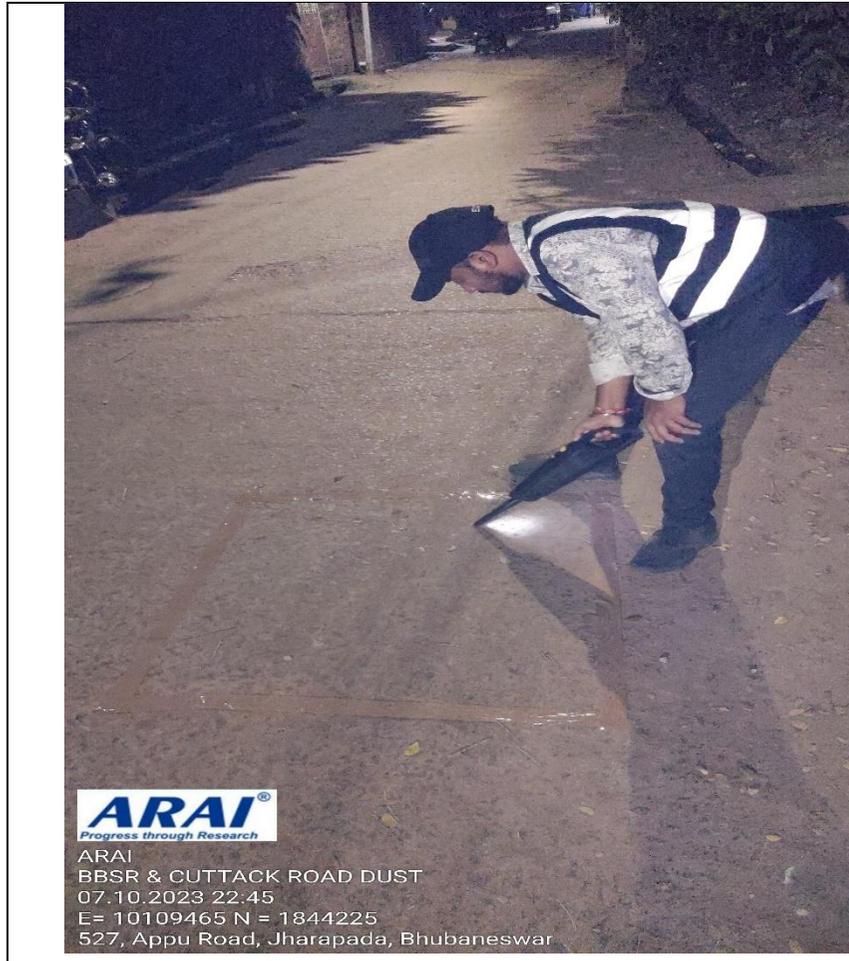
*Figure G.127 Construction activity in Bhubaneswar in January 2022 and December 2022*

Photographs taken during primary data collection surveys in Bhubaneswar region





Photographs taken during road dust sampling at Bhubaneswar



Photographs showing activities in Bhubaneswar region



Open Waste

Analysis of satellite derived fires data

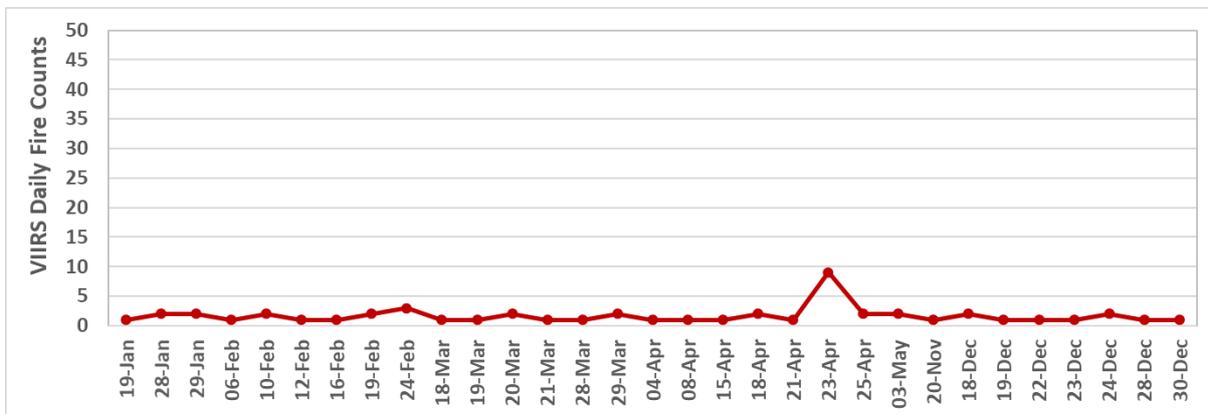


Figure G6: Time-series of daily fire counts observed over Bhubaneswar-Cuttack region during baseline year 2022.

### Annexure-H: Assumptions for Transport Sector

**Table H.1: Considerations/Assumptions for quantification of vehicular emissions for four scenarios in 2027**

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
1	Emission Standards	All Four Scenarios	Implementation of BS-VI standards starting April, 2020						
2	Roll-out of E20 fuel	NFC 2027	NA	NA	NA		NA	NA	NA
		BAU 2027	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
		SC_I_2027	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
		SC_II_2027	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
3	Increased EV Penetration	NFC 2027	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 1% between 2026-32	NA	NA	NA	NA	NA	NA
		BAU 2027	EV penetration in newly registered vehicles a) 10% between 2021-25 b) 14% between 2026-32	EV penetration in newly registered vehicles a) 10% between 2021-26 b) 16%	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 2%	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 7%	NA	NA	EV penetration in newly registered vehicles a) 1% between 2021-26 b) 4%

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				between 2027-31	between 2027-31	between 2027-31			between 2027-31
		<b>SC_I_2027</b>	EV penetration in newly registered vehicles a) 12% between 2021-25 b) 22% between 2026-32	EV penetration in newly registered vehicles a) 12% between 2021-26 b) 18% between 2027-31	EV penetration in newly registered vehicles a) 3% between 2021-26 b) 7% between 2027-31	EV penetration in newly registered vehicles a) 3% between 2021-26 b) 13% between 2027-31	NA	NA	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 9% between 2027-31
		<b>SC_II_2027</b>	EV penetration in newly registered vehicles a) 14% between 2021-25 b) 37% between 2026-32	EV penetration in newly registered vehicles a) 16% between 2021-26 b) 37% between 2027-31	EV penetration in newly registered vehicles a) 4% between 2021-26 b) 13% between 2027-31	EV penetration in newly registered vehicles a) 6% between 2021-26 b) 27% between 2027-31	NA	NA	EV penetration in newly registered vehicles a) 5% between 2021-26 b) 18% between 2027-31
<b>3</b>	<b>Increased CNG Penetration</b>	<b>NFC 2027</b>	NA	CNG penetration in newly registered vehicles a) 90% between	NA	CNG penetration in newly registered vehicles a) 10% between	CNG penetration in newly registered vehicles a) 5% between	NA	NA

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				2021-25 b) 90% between 2026-32		2021-25 b) 10% between 2026-32	2021-25 b) 5% between 2026-32		
		<b>BAU 2027</b>	NA	CNG penetration in newly registered vehicles a) 80% between 2021-25 b) 74% between 2026-32	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 10% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 13% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 5% between 2026-32	NA	CNG penetration in newly registered vehicles a) 0% between 2021-25 b) 2% between 2026-32
		<b>SC_I_2027</b>	NA	CNG penetration in newly registered vehicles a) 78% between 2021-25 b) 67% between 2026-32	CNG penetration in newly registered vehicles a) 1% between 2021-25 b) 15% between 2026-32	CNG penetration in newly registered vehicles a) 1% between 2021-25 b) 2% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 5% between 2026-32	NA	CNG penetration in newly registered vehicles a) 1% between 2021-25 b) 6% between 2026-32
		<b>SC_II_2027</b>	NA	CNG penetration in newly registered vehicles a) 74%	CNG penetration in newly registered vehicles a) 2%	CNG penetration in newly registered vehicles a) 20%	CNG penetration in newly registered vehicles a) 5%	NA	CNG penetration in newly registered vehicles a) 1%

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				between 2021-25 b) 53% between 2026-32	between 2021-25 b) 15% between 2026-32	between 2021-25 b) 20% between 2026-32	between 2021-25 b) 10% between 2026-32		between 2021-25 b) 5% between 2026-32
6	NMT Share	NFC 2027	No VKT reduction by 2027	No VKT reduction by 2027	No VKT reduction by 2027	No VKT reduction by 2027	NA	NA	No VKT reduction by 2027
		BAU 2027	0.25% VKT reduction by 2027	0.25% VKT reduction by 2027	0.25% VKT reduction by 2027	0.25% VKT reduction by 2027	NA	NA	0.25% VKT reduction by 2027
		SC_I_2027	0.5% VKT reduction by 2027	0.5% VKT reduction by 2027	0.5% VKT reduction by 2027	0.5% VKT reduction by 2027	NA	NA	0.5% VKT reduction by 2027
		SC_II_2027	1% VKT reduction by 2027	1% VKT reduction by 2027	1% VKT reduction by 2027	1% VKT reduction by 2027	NA	NA	1% VKT reduction by 2027
4	Mass Rapid Transit System (MRTS)/ Metro	NFC 2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		BAU 2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		SC_I_2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		SC_II_2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
5	Improved Public Transport/ VKT Reduction (%)	NFC 2027	No improvement in public transport						
		BAU 2027	0.54% VKT reduction by year 2027	1.12% VKT reduction by year 2027	0.57% VKT reduction by year 2027	1.61% VKT reduction by year 2027	NA	NA	25 buses per lakh population and all new buses

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
									procured would be Electric vehicles
		<b>SC_I_2027</b>	0.65% VKT reduction by year 2027	1.35% VKT reduction by year 2027	0.68% VKT reduction by year 2027	1.93% VKT reduction by year 2027	NA	NA	30 buses per lakh population and all new buses procured would be Electric vehicles
		<b>SC_II_2027</b>	0.87% VKT reduction by year 2027	1.81% VKT reduction by year 2027	0.91% VKT reduction by year 2027	2.58% VKT reduction by year 2027	NA	NA	40 buses per lakh population and all new buses procured would be Electric vehicles
<b>6</b>	<b>Improve and strengthen PUC programme</b>	<b>NFC 2027</b>	No Change in super-emitters percentage						
		<b>BAU 2027</b>	No Change in super-emitters percentage						
		<b>SC_I_2027</b>	10% Reduction in super-emitters percentage compared to NFC 2027						
		<b>SC_II_2027</b>	25% Reduction in super-emitters percentage compared to NFC 2027						

**Table H.2: Considerations/Assumptions for quantification of vehicular emissions for four scenarios in 2032**

Sr. No.	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
1	<b>Emission Standards</b>	<b>All Four Scenarios</b>	Implementation of BS-VI standards starting April, 2020						
2	<b>Roll-out of E20 fuel</b>	<b>NFC</b>	NA	NA	NA		NA	NA	NA
		<b>BAU 2032</b>	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
		<b>SC_I_2032</b>	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
		<b>SC_II_2032</b>	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
3	<b>Increased EV Penetration</b>	<b>NFC</b>	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 1% between 2026-32	NA	NA	NA	NA	NA	NA
		<b>BAU 2032</b>	EV penetration in newly registered vehicles a) 10% between 2021-25 b) 17%	EV penetration in newly registered vehicles a) 10% between 2021-26 b) 20%	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 3%	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 12%	NA	NA	EV penetration in newly registered vehicles a) 1% between 2021-26 b) 7% between 2027-31

Sr. No.	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
			between 2026-32	between 2027-31	between 2027-31	between 2027-31			
		<b>SC_I_2032</b>	EV penetration in newly registered vehicles a) 12% between 2021-26 b) 30% between 2027-31	EV penetration in newly registered vehicles a) 12% between 2021-26 b) 26% between 2027-31	EV penetration in newly registered vehicles a) 3% between 2021-26 b) 11% between 2027-31	EV penetration in newly registered vehicles a) 3% between 2021-26 b) 23% between 2027-31	NA	NA	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 14% between 2027-31
		<b>SC_II_2032</b>	EV penetration in newly registered vehicles a) 14% between 2021-26 b) 57% between 2027-31	EV penetration in newly registered vehicles a) 16% between 2021-26 b) 57% between 2027-31	EV penetration in newly registered vehicles a) 4% between 2021-26 b) 22% between 2027-31	EV penetration in newly registered vehicles a) 6% between 2021-26 b) 48% between 2027-31	EV penetration in newly registered vehicles a) NA between 2021-26 b) 15% between 2027-31	NA	EV penetration in newly registered vehicles a) 5% between 2021-26 b) 28% between 2027-31
<b>3</b>	<b>Increased CNG Penetration</b>	<b>NFC</b>	NA	CNG penetration in newly registered vehicles a) 90%	NA	CNG penetration in newly registered vehicles a) 10%	CNG penetration in newly registered vehicles a) 5%	NA	NA

Sr. No.	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				between 2021-26 b) 90% between 2027-31		between 2021-26 b) 10% between 2027-31	between 2021-26 b) 5% between 2027-3		
		<b>BAU 2032</b>	NA	CNG penetration in newly registered vehicles a) 80% between 2021-26 b) 70% between 2027-31	CNG penetration in newly registered vehicles a) 10% between 2021-26 b) 10% between 2027-31	CNG penetration in newly registered vehicles a) 5% between 2021-26 b) 10% between 2027-31	CNG penetration in newly registered vehicles a) 5% between 2021-26 b) 10% between 2027-31	NA	CNG penetration in newly registered vehicles a) 0% between 2021-26 b) 5% between 2027-31
		<b>SC_I_2032</b>	NA	CNG penetration in newly registered vehicles a) 78% between 2021-26 b) 64% between 2027-31	CNG penetration in newly registered vehicles a) 1% between 2021-26 b) 15% between 2027-31	CNG penetration in newly registered vehicles a) 10% between 2021-26 b) 20% between 2027-31	CNG penetration in newly registered vehicles a) 5% between 2021-26 b) 15% between 2027-31	NA	CNG penetration in newly registered vehicles a) 1% between 2021-26 b) 5% between 2027-31
		<b>SC_II_2032</b>	NA	CNG penetration in newly registered vehicles	CNG penetration in newly registered vehicles	CNG penetration in newly registered vehicles	CNG penetration in newly registered vehicles	NA	CNG penetration in newly registered vehicles

Sr. No.	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses	
				a) 74% between 2021-26 b) 33% between 2027-31	a) 2% between 2021-26 b) 20% between 2027-31	a) 20% between 2021-26 b) 40% between 2027-31	a) 5% between 2021-26 b) 2% between 2027-31		a) 1% between 2021-26 b) 10% between 2027-31	
6	NMT Share	NFC	No VKT reduction by 2032	No VKT reduction by 2032	No VKT reduction by 2032	No VKT reduction by 2032	NA	NA	No VKT reduction by 2032	
		BAU 2032	1% VKT reduction by 2032	1% VKT reduction by 2032	1% VKT reduction by 2032	1% VKT reduction by 2032	NA	NA	1% VKT reduction by 2032	
		SC_I_2032	2% VKT reduction by 2032	2% VKT reduction by 2032	2% VKT reduction by 2032	2% VKT reduction by 2032	NA	NA	2% VKT reduction by 2032	
		SC_II_2032	4% VKT reduction by 2032	4% VKT reduction by 2032	4% VKT reduction by 2032	4% VKT reduction by 2032	NA	NA	4% VKT reduction by 2032	
4	Mass Rapid Transit System (MRTS)/ Metro	NFC	No MRTS							
		BAU 2032	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 1 km c) Daily ridership: 47717				NA	NA	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 1 km c) Daily ridership: 47717	

Sr. No.	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
		<b>SC_I_2032</b>	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 95434				NA	NA	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 95434
		<b>SC_II_2032</b>	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 102797				NA	NA	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 102797
<b>5</b>	<b>Improved Public Transport/ VKT Reduction (%)</b>	<b>NFC</b>	No improvement in public transport						
		<b>BAU 2032</b>	0.53% VKT reduction by year 2032	1.11% VKT reduction by year 2032	0.53% VKT reduction by year 2032	1.51% VKT reduction by year 2032	NA	NA	30 buses per lakh population and all new buses procured would be

Sr. No.	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
									Electric vehicles
		<b>SC_I_2032</b>	0.80% VKT reduction by year 2032	1.69% VKT reduction by year 2032	0.81% VKT reduction by year 2032	2.28% VKT reduction by year 2032	NA	NA	45 buses per lakh population and all new buses procured would be Electric vehicles
		<b>SC_II_2032</b>	1.08% VKT reduction by year 2032	2.29% VKT reduction by year 2032	1.09% VKT reduction by year 2032	3.09% VKT reduction by year 2032	NA	NA	60 buses per lakh population and all new buses procured would be Electric vehicles
<b>6</b>	<b>Improve and strengthen PUC programme</b>	<b>NFC</b>	No Reduction in super-emitters percentage						
		<b>BAU 2032</b>	10% Reduction in super-emitters percentage compared to NFC 2032						
		<b>SC_I_2032</b>	25% Reduction in super-emitters percentage compared to NFC 2032						
		<b>SC_II_2032</b>	50% Reduction in super-emitters percentage compared to NFC 2032						

## Annexure-I: Breakpoints for AQI

**Table J.1: Breakpoints for Air Quality Index (AQI) Scale 0 to 500 (Source: CPCB, 2015)**

AQI Category	AQI Range	PM <sub>2.5</sub>	PM <sub>10</sub>	NO <sub>2</sub>	SO <sub>2</sub>	O <sub>3</sub>	CO
	Unit less	µg/m <sup>3</sup>	mg/m <sup>3</sup>				
Good	0-50	0-30	0-50	0-40	0-40	0-50	0-1
Satisfactory	51-100	31-60	51-100	41-80	41-80	51-100	1.1-2.0
Moderate	101-200	61-90	101-250	81-180	81-380	101-168	2.1-10.0
Poor	201-300	91-120	251-350	181-280	381-800	169-208	10.1-17.0
Very poor	301-400	121-250	351-430	281-400	801-1600	209-748	17.1-34.0
Severe	401-500	251+	431+	401+	1601+	748+	34.1+

---- END OF THE REPORT---